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UNITED STATES ARMY

TRAINING AND DOCTRINE COMMAND

UNITED STATES ARMY MATERIEL COMMAND

LIGHT HELICOPTER FAMILY

TRADE-OFF ANALYSIS

APPENDIX N

VOLUME IV

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Speed	Structures	System	Reliability	Analysis	Subsystem
Cruise	Deployability	Deploy	Maintainability	Self-deploy	Structure
OEI	Deployment	Engine	Performance	Vertical flight	Gross
APU	Maneuverability	OBOGS	Efficiency	Agility	Weight
				NBC	

(Cont'd on reverse.)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

During the Light Helicopter Family (LHX) Trade-Off Analysis (TOA), 10 major areas of aircraft performance and subsystems were evaluated. These 10 substudies formed the following Annexes: N-I Light Helicopter Family (LHX) Subsystems; N-II Structures - Pertinent Issues and Systems Characteristics; N-III LHX Deployability; N-IV Vertical Flight Analysis; N-V Maneuverability/Agility Analysis; N-VI Level Flight Analysis - Speed; N-VII Level Flight Analysis - Cruise Efficiency; N-VIII Level Flight Analysis - One Engine Inoperative (OEI); N-IX Multiple Attribute Decision Making Analysis;

(Cont'd on reverse.)

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BLOCK 19: (Cont'd)	V(BR)	Electrical	Hydraulic	Refuel	Acceleration	TOA
ABC	VROC	Pneumatic	Helicopter	Cargo	Deceleration	
Compound	Hoist	Airframe	Composite	Deicing	Icing	

Cont.

BLOCK 20: (Cont'd)

N-X Aircraft Performance and Engine Power Margin. These ten substudies with a summary formed this volume of the LHX TOA Report.

MAJOR FINDINGS/CONCLUSIONS REACHED IN THIS VOLUME INCLUDE: (1) The helicopter candidate is the least costly and lowest weight configuration examined; (2) In terms of maneuverability/agility, the helicopter candidate is better in the 0- to 120-knot range. The tilt rotor is better above 120 knots; (3) In terms of speed, only the tilt rotor has the potential to increase productivity and match the performance of threat tilt rotor development; (4) All candidates have an en route, single-engine flight capability at design mission gross weight; (5) Although providing the LHX with a built-in structural and engine-power margin adversely impacts weight, fuel consumption, and cost, potential gains in improved mission performance capability and system growth potential warrant providing the LHX with such features; (6) Onboard power sources should include: (a) An auxiliary power unit for cold climate starting and to provide power for maintenance; (b) A pneumatic system sized to provide crew chemical and biological agent protection; (c) Current modular hydraulics to reduce maintenance requirements; (7) An integrated system for generating oxygen and nitrogen should be installed to provide additional CB protection for the crew, to provide flight at 18,000 feet, and to provide sufficient nitrogen to prevent fuel cell fire and explosions; (8) A hybrid collective NBC protection system combined with a filtered/cooled air overpressure system and individual CB protective ensembles with provision for suit/facepiece cooling should be installed; (9) Some built-in anti-ice/deice devices for the engines and windshields are necessary, but further capability should be provided via kits; (10) The tri-service standard flight data recorder should be installed; (11) Cargo hooks with the following capabilities should be installed: (a) SCAT - single-hook - 3,000 lbs.; (b) Utility - multi-hook - 4,000 lbs.; (12) Internal cargo loads necessitate a tiedown ring pattern; (13) The current 28-volt DC-powered rescue hoist is preferred for the Utility (none for SCAT); (14) Maximum practical advanced composite materials in airframe structures should be utilized; (15) External tank capability for the LHX-SCAT and internal auxiliary tanks for the LHX-Utility should be provided for self-deployment over ranges of up to 1,260 nm. (16) Aircraft design should maximize the number of aircraft that can be transported by Air Force assets. At the same time, the design should minimize loading and unloading times, ground crew size, and amount of GSE required; (17) Ship transportability should be a design consideration.

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UNITED STATES ARMY TRAINING AND DOCTRINE COMMAND

UNITED STATES ARMY MATERIEL COMMAND

LIGHT HELICOPTER FAMILY TRADE-OFF ANALYSIS

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LIGHT HELICOPTER FAMILY
TRADE-OFF ANALYSIS
(LHX TOA)

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GLOSSARY (U)

AAELSS	active arm external load stabilization system
ABC	advancing blade concept
ABC-C	advancing blade concept-compound
ACAP	Advanced Composite Airframe Program
Ada	Department of Defense standard computer language after January 1984
ADDCS	aircraft decontamination deicing and cleaning system
ADTE	automatic diagnostic test equipment
AF	airframe
AFCS	automatic flight control system
AGB	accessory gear box
AGL	above ground level
AGPU	aviation ground power unit
AH-64A	Apache attack helicopter
AHIP	Army Helicopter Improvement Program
AHS	advanced scout helicopter
AI	anti-icing
ALSE	aviator life support system
AMC	Army Materiel Command
ANOVA	analysis of variance
APS	air particle separator
APU	auxiliary power unit
ASE	aircraft survivability equipment
ASH	advanced scout helicopter

A129	Augusta Model 129 Scout-Attack (SCAT) Derivative
BIT	built-in test
CE	cruise efficiency
COEA	cost and operational effectiveness analysis
CRP	contingency rated power
dhe/dt	change in altitude relative to time
dia	diameter
D/L	disk loading
ECS	environmental control system
ECU	environmental control unit
EMI	electromagnetic interference
EMP	electromagnetic pulse
Eng	engine
Eng Pwr	engine power
ESSS	external stores support system
F	Fahrenheit
fpm	feet per minute
ft	feet
FUL	fixed useful load
FW	fixed wing
g	acceleration of gravity
GSE	ground support equipment
GW	gross weight
HACES	Helicopter Air Combat Effectiveness Simulation
HEL	helicopter
HEL-C	compound helicopter

HELMS	helicopter mission survivability model
HELO	helicopter
HELO-C	compound helicopter
HIGE	hover in ground effect
HIRSS	hover infrared suppressor
HOGE	hover out of ground effect
HP	horse power
HPCB	high-pressure chemical, biological
HPH	high-performance hoist
IOC	initial operational capability
IRP	intermediate rated power (30-minute rating)
JVX	joint vertical lift aircraft
kt	knots
KTAS	knots true airspeed
lb	pounds
LHX	Light Helicopter Family
LHX-U	Light Helicopter Family-Utility aircraft
LRU	line replaceable units
m	meter
M/A	maneuverability/agility
MA	maintenance action
MAX	maximum
MCP	maximum continuous power
MDGW	mission design gross weight
MEP	mission equipment package
MGB	main gear box

MGW	maximum gross weight
MGW	mission gross weight
MH	man-hour
mm	millimeter
MMH	maintenance man-hour
MM&T	manufacturing methods and technology
MMW	millimeter wave (often refers to MMWR)
MOS	military occupational specialty
MR	maintenance ratio (total number of man-hours of maintenance performed divided by the total flight time during the given period)
MRP	maximum rated power
MSN	mission
MSV	maximum sustained velocity
MTBMAF	mean time between mission-affecting failures
MTBUMA	mean time between unscheduled maintenance actions
MTTR	mean time to repair
MU	memory unit
MWO	modification work order
NATO	North Atlantic Treaty Organization
NBC	nuclear, biological, and chemical
NOE	nap of the earth
OBOGS	onboard oxygen generating system
OBST	obstacle
OEI	one engine inoperative
PD	preliminary design
PETS	portable engine test stand

PMI	polymethacrylimide (Rohacell) rigid plastic foam
Ps	specific excess power
PSE	peculiar support equipment
QCA	quick-change assembly
RC	rate of climb
R/C	rate of climb
RCCB	remote-control circuit breaker
R&D	research and development
R&M	reliability and maintainability
ROC	required operational capability
RSI	rationalization, standardization, and interoperability
S-75	Sikorsky Model 75 Utility Derivative
SAR	search and rescue
SCAMP	self-propelled crane, aircraft maintenance and positioning
SCAS	stability control augmentation system
SCAT	scout-attack
SDC	shaft-driven compressor
SDGW	structural design gross weight
SEAD	suppression of enemy air defense
SFDR	standard flight data recorder
Slf	sustained load factor
SLS	sea level standard
SMA	scheduled maintenance actions
SMU	survivable memory unit
SOAP	Spectral Oil Analysis Program
SPEMS	self-propelled elevating maintenance stand

STE	special test equipment
TAMP	tactical aircraft maintenance platform
TBO	time between overhaul
THE	transportable helicopter
Tlf	transient load factor
TMDE	test, measurement, and diagnostic equipment
TOA	trade-off analysis
TOD	trade-off determination
TOE	tables of organization and equipment
TOGW	takeoff gross weight
TOPSIS	technique for ordered preference by similarity to ideal solution
T/R	tilt rotor
TR	tilt rotor
TRP	troop(s)
-U	as in LHX-U (utility)
UH	utility helicopter
UH-1 and UH-60	utility helicopter (UH-1 Iroquois or Huey and UH-60 Black Hawk)
UMA	unscheduled maintenance actions
USAAVNC	US Army Aviation Center
USAF	US Air Force
USMC	US Marine Corps
USN	US Navy
UTIL	utility
UTTAS	Utility Tactical Transport Helicopter
V	velocity (airspeed)

V(BR)	best range airspeed
V(.99BR)	.99 best range airspeed
V(DASH)	same as V(IRP) - intermediate rated power airspeed
V(BE)	best endurance airspeed
V(IRP)	intermediate rated power airspeed
V(MCP)	maximum continuous power airspeed
VF	vertical flight
VROC	vertical rate of climb
WE	weight empty
wt	weight

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APPENDIX N

<u>AIRCRAFT PERFORMANCE AND SUBSYSTEMS</u>

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APPENDIX N

AIRCRAFT PERFORMANCE AND SUBSYSTEMS

The following 10 major paragraphs outline the 10 main areas of study that the group evaluating aircraft performance and subsystems completed during the Trade-Off Analysis (TOA). Each major paragraph title corresponds to the annex of this appendix that more fully addresses the subject. The annex number, except for being in Roman numerals, is exactly the same as the major paragraph number. (NOTE: A major caveat to this appendix--this is only a review/summation of the 10 studies much more fully presented in the annexes. For a complete discussion of any subject, one must refer to the applicable annex.)

N-1. LIGHT HELICOPTER FaMILY (LHX) SUBSYSTEMS.

a. Subsystems. The following subsystems are addressed in this section of the TOA report.

(1) Onboard power sources.

(a) Electrical subsystem.

(b) Pneumatic subsystem.

(c) Hydraulic subsystem.

(2) Environmental control system (ECS).

(3) Onboard oxygen generating system (OBOGS).

(4) Anti-icing/deicing system.

(5) Standard flight data recorder (SFDR).

(6) Onboard refueling system.

(7) Fire detection, warning, and extinguishing (FDWE) system.

(8) Cargo handling and rescue hoist.

b. Findings (Subsystems).

(1) The auxiliary power unit (APU) (versus the battery) provides the greatest operational advantage in terms of reduced fuel usage, dispatch reliability, flight safety, and field maintenance.

(2) The electrical subsystem design is completely dependent upon the mission equipment package (MEP), weapon system, and icing requirements. Also, this subsystem has to be designed to handle the maximum continuous power as well as the peak power loads even though some functions (icing requirements) may be provided in kit form.

(3) Pneumatic subsystem sizing is significantly dependent upon the crew chemical and biological (CB) protection level required. If cockpit overpressure protection is necessary following combat damage, then considerable weight and power penalties are incurred.

(4) Fly-by-light/wire flight controls will reduce the number of hydraulic actuators resulting in improved reliability, availability, and maintainability (RAM) characteristics and weight savings. However, weight reductions associated with the use of composities for hydraulic components are high-risk and may not be cost-effective as the hydraulic subsystem is currently less than one percent of the aircraft empty weight.

(5) The hybrid ECS (cockpit overpressure plus individual suits) provides maximum aircrew CB protection during combat; when aircrews do not wear protective clothing (peacetime) sufficient cooled/heated air is available.

(6) The OBOGS output will be sufficient to permit the LHX crew to fly at 18,000 feet; also, sufficient nitrogen will be available from the nitrogen inerting unit (NIU) section of the OBOGS to prevent fuel cell fires or explosions.

(7) For icing requirements, a weight savings of 62 to 75 lb will be realized by provisioning via kits.

(8) The required characteristics for crash investigations are identified in a draft tri-service specification for an SFDR. These include the ability to collect, process, and retain in a crash-survivable memory parameters necessary for a comprehensive assessment of the mechanical and performance status of the aircraft as well as maintenance-related data in a nonsurvivable (crash) memory. The commonality of the microprocessors of the MEP and the SFDR, both using the same software (Ada), will ensure maximum exchange of information and ease of integration (MEP, SFDR, and fault detection/locator system (FD/LS)).

(9) The onboard refueling system will be configured as a built-in design due to its low weight (3 lb) and operational benefits (saves time/work). The system will be compatible with NATO standard refueling nozzles and procedures.

(10) The candidate FDWE system for all LHX configurations consists of automatic sensing, logic processing, and extinguishing of propulsion system fires. The MEP contains the logic-processing capability. The UH-60A FDWE system weighs 30.6 lb; the LHX FDWE system will weigh 9-10 lb.

(11) Load stabilization is desired to prevent external cargo oscillations while promoting high-maneuver nap-of-the-earth (NOE) flight. Load stabilization is not required for the scout-attack (SCAT) cargo hook. The capability for precision hover (desired for cargo/rescue) is already incorporated into the MEP for other reasons. The preferred method of mounting the rescue hoist is to have the capability for swinging the payload into the cabin.

N-2. STRUCTURES - PERTINENT ISSUES AND SYSTEM CHARACTERISTICS.

a. Preliminary Structures Issues.

(1) Airframe.

(2) Hub and hinge.

(3) Rotor blade.

(4) Landing gear.

b. Related Structure Issues.

(1) Decontamination. Because the use of nuclear, biological, and chemical (NBC) weapons has become a tactical reality, the LHX must be capable of safe, efficient operation and support in a contaminated environment. Not only must the crew be protected from NBC hazards, the entire aircraft must be designed to both minimize exposure to NBC contaminants and to facilitate decontamination after an exposure has occurred.

(2) Structural/retirement life. The retirement life for potential candidate derivative aircraft airframes must be considered along with the projected retirement life of new system designs.

(3) Battle damage repair. As the helicopter system becomes less vulnerable to ballistic threat, the issue of battle damage repair has to be considered as a part of the reliability and maintainability characteristics for the LHX.

c. Structural Findings.

(1) Ranking of alternative approaches. A comparison of the two major technical approaches to airframe structures is provided in figure N-1. The final ranking of the alternatives based on the relative ranking of the specific characteristics is shown in figure N-2.

(2) Rationale for ranking of alternatives. Composite airframe technology provides a significant advantage over metallic technology from a weight viewpoint. Weight savings on the order of 27 percent in the airframe are projected. Airframe costs for 1970 and new metallic airframe technology are advantageous as compared to 1960s' technology because of improved system

reliability which results in lower operating and support costs. Composite airframes, however, provide a significant reduction in production costs as well as an improvement in operating and support costs. Although metallic airframe structures are certainly producible, composite airframe structures offer the advantage of reduced manpower requirements and significant improvements in the ability to tailor the structural design to produce the desired military characteristics.

	New Metallic Airframe	New Composite Airframe
Weight		X
Cost		X
Damage tolerance/durability		X
RAM		X
Ballistics		X
NBC	X	
Crashworthiness		
Detectability		X
Lightning	X	
Risk	X	
Test, measurement, and diagnostic equipment (TMDE)	X	
Training	X	
Integrated logistics support (ILS)		X
RSI		

X = Superior attribute/capability.

Figure N-1. Airframe ratings.

1. New composite airframe.
2. ACAP derivative.
3. New metal airframe.
4. 1970s' technology derivative.

Figure N-2. Recommended ranking of alternatives.

d. Recommended Alternative Rotor Hub Systems. The recommended alternative for the hub and hinge assembly is the bearingless composite variant. The weight, reliability, and maintainability advantages of this approach make the increased risk acceptable. The reason for adverse risk is the dependence of this approach on the completion of the integrated technology rotor (ITR) program for technical demonstration. It should be noted that the ITR program should provide aeromechanic and performance benefits that cannot be addressed at this time. The bearingless composite variant is applicable to all LHX configurations. The baseline composite approach will provide a safe fall-back position. However, the bearingless composite hub is recommended due to projected technological advances and operational benefits that will accrue from technology that will occur in the mid-1980s.

e. Recommended Alternative Rotor Systems. The recommended alternative for the main rotor blade assembly is the baseline composite which features all composite construction. The fatigue life and reliability and maintainability advantages of this approach, combined with its complete operational demonstration, make it the clear choice.

f. Description of the Recommended Landing Gear Alternative.

(1) A ranking of the candidate landing gear configuration with respect to achieving overall system characteristics is provided below:

Landing Gear Configurations

(a) Composite, fully retractable, wheel landing gear.

(b) Composite, partially retractable wheel landing gear enclosed with fairings.

(c) Composite, fixed wheel landing gear.

(d) Metallic, fully retractable wheel landing gear.

(e) Metallic, partially retractable wheel landing gear enclosed with fairings.

(f) Metallic, fixed wheel landing gear.

(2) In ranking the candidate configurations, it was determined that the most desirable landing gear configuration in terms of weight, cost, producibility, drag, damage tolerance, and RAM was the composite, fully retractable wheel landing gear. It was further assessed that the estimated 13-percent weight savings gained through the utilization of composite makes this configuration the most competitive. The configuration has a drawback in that it is the least survivable if a crash were to occur with the gear in the fully retracted mode. However, in an emergency, the automatic extension mechanism would extend the gear at least partially to provide some energy attenuation.

(3) Should composites not provide the weight savings needed to overcome the weight penalty imposed due to retractability, a metallic, fully retractable wheel landing gear would be the most likely candidate to achieve overall system characteristics. Though a 10-percent weight and cost penalty is imposed over the fixed wheel gear design, it is anticipated that the reduction in drag, vulnerability, detection, and decontamination would offset these penalties. Additionally, no difference in engineering characteristics for the helicopter, compound helicopter, ABC, and tilt rotor exists.

g. Findings: Airframe Structures.

(1) The use of composite materials and construction techniques is equally applicable to all five LHX configurations.

(2) The preferred approach is the maximum practical application of advanced composite materials to the LHX airframe due to significant weight, cost, durability, and detectability advantages.

(3) The preferred approach for the hub and hinge assembly is the bearingless composite variant due to weight, reliability, maintenance, aeromechanical, and performance benefits.

(4) The all-composite rotor blades are preferred over the metallic spar variant as costs, fatigue life, damage tolerance, aerodynamic tailoring, and reliability are inherent factors of the composite blade. However, the weight of the composite rotor blade cannot be reduced as certain mass properties must be present to maintain autorotational characteristics.

(5) The most desirable landing gear configuration in terms of weight, costs, producibility, and drag is the fully retractable wheel landing gear of composite construction.

N-3. LIGHT HELICOPTER FAMILY (LHX) DEPLOYABILITY. This portion of the TOA report discusses LHX alternatives for self-deployability, air transportability, ship transportability, and shipboard operations. Although the

LHX-SCAT is a relatively small aircraft (compared to the AH-64A) and that would tend to imply easy transportability, the MEP is extensive and sensor locations, coupled with designing for crew accommodation, rotor clearances, etc., dictate a height requirement which complicates rapid load/off-load for air transport.

a. Self-Deployability.

(1) Requirement. The LHX Systems Attributes Document (SAD) calls for the LHX to be self-deployable for 740 nautical miles (nm) (plus 10-percent reserve fuel) for the baseline configuration, with a desired ferry range of 1,240 nm (South Atlantic route). The SAD further requires a 99-percent (.99) probability of success. The 2,100-nm Pacific mission is also discussed but not specified in the SAD.

(2) Recommended approach. The option of adding external tank capacity (for the LHX-SCAT) and internal auxiliary tanks (for the LHX-Utility) is recommended for the following reasons:

(a) Such hardware provisions are current technology.

(b) There is only a slight weight penalty to be carried on non-deployment missions.

(c) This option is independent of availability of other services (USN, USAF) assets and closely coordinated linkup requirements.

(d) This option can readily be used for other extended-range missions, when desired.

b. Air Transportability. The pertinent issues concerning air transportability are designing the LHX (SCAT and Utility) so that all subsystem components function properly and still meet the air transport load/off-load times and designing the LHX-SCAT (and Utility variance) configurations low enough to clear the C-141 ceiling height and still retain the crash force absorption in the landing gear struts. For the LHX-SCAT, the 30mm cannon must be located near the nose for adequate up/down swiveling. The pilot's night vision system must be located above the weapon, and the EOTADS must be located away from the gun flash. The millimeter wave (MMW) radar antenna must be top side-mounted for full effectiveness. All this, coupled with sufficient rotor-to-fuselage clearance (for the helicopter configuration), forces LHX height growth into the 103 inches of usable height of the C-141 aircraft. The floor depth and fuselage-to-ground clearance can be minimized only at a serious cost to crashworthiness. This creates the necessity to use landing gear kneeling to permit ramp crest clearance over the 15-degree floor-to-ramp hinge point in the C-141 (see figure N-3).

	C-130H	C-141B	C-17	C-5A
Cargo compartment (usable)				
Main floor length (inches)	481	1,114	1,056	1,459
Main floor width (inches)	111	111	216	216
Ceiling height (inches)	104	103	148	108
				156
Number of LHX-SCAT helicopters	2	4	6-8	10-12

NOTES:

a. MIL-A-8421F requires a minimum of 6 inches clearance between payload and aircraft, except the floor, during loading and flight (applicable to all models).

b. C-5A has "lip-roof" compartment, width is 228 inches to height of 114 inches, tapering to 156 inches width at 162 inches height.

c. C-17, initial operational capability scheduled for fiscal year 92.

Figure N-3. USAF transport aircraft characteristics.

c. Findings.

(1) Self-deployment.

(a) In the self-deployment mode, the tilt rotor is the preferred system due to its superior range and speed which allows route flexibility, reduction of en route refuel stops, and improved ferry mission time.

(b) All LHX candidates meet the desired 1,240-nm ferry range, thereby allowing route flexibility (both northern and southern routes to Europe) which would result in avoidance of en route adverse weather or possible threat forces.

(c) The preferred self-deployment mode is the use of auxiliary tanks as opposed to air-to-air refueling, in-flight towing, integral fuel tank capacity, or ship hopping.

(d) Over an extended period, the speed and range advantage of the tilt rotor is significantly reduced since the departure rate of aircraft becomes the dominant factor for force buildup.

(e) Many factors affect force buildup (arrival rate) in theater; i.e., weather, combat attrition, in-flight failures, range and speed of aircraft, crew rest periods, pre-positioning of flight crews, and airport facilities (aircraft parking spaces, refueling rates, and crew quarters).

(2) Air transport.

(a) The helicopter and the ABC aircraft are the preferred systems because twice as many may be loaded (in the C-141B) as other candidates and with reasonable preparation times as well.

(b) Although the number of aircraft which may be transported by the C-141B carrier is important, other factors such as load/unload time, ground crew size, and the amount of ground support equipment (GSE) are of equal importance.

(c) The greater range and speed advantage of the air transporter over the self-deployment mode significantly improves route flexibility and response time. Recycling assets (C-141B) by using backhaul missions will greatly reduce the number of air transporters required for airlift operations. However, the air transport mode complements the self-deployment capability but does not replace it.

(3) Shipboard operations and transportability. The level of LHX marinization required for shipboard operations and transportability has not been adequately defined to date. Therefore, specific trade-offs affecting weight, costs, and technical risks are not known.

N-4. VERTICAL FLIGHT (VF) ANALYSIS.

a. Purpose. The vertical flight (VF) analysis is intended to present the costs in weight and dollars to achieve increased performance at altitudes above 4,000 feet (ft) pressure altitude. The trade-off determination (TOD) has developed baseline designs from which the delta weight and costs are discussed. The baseline designs include a derivative (A129 and S75), helicopter, compound helicopter, advancing blade concept (ABC), compound ABC, and a tilt rotor (TR). The SCAT baselines were designed (modified for derivatives) to meet a vertical rate of climb (VROC) of at least 500 feet per minute (fpm) at 4,000 ft/95° Fahrenheit (F) at .95 intermediate rate power (IRP). The Utility designs were specified to meet a hover out-of-ground effect (HOGE) level at this same altitude, temperature, and power condition. In addition, the SCAT designs had to meet the requirements of the security mission specified for the Middle East (mission 16), and the Utility designs

had to meet the requirements of the special operations forces (SOF) insertion mission in the Middle East (mission 35). The SCAT payload was specified as 1,030 pounds (lb) while the Utility payload was set at 1,530 lb. The designs which evolved from the TOD effort are presented in figure N-4.

		4,000 ft/95°F	95% IRP	
Design	Type	Design Gross Weight (lb)	VROC (fpm)	Payload (lb)
Derivative				
A129	SCAT	8,884	500	891
S75	Utility	10,930	0	1,440
Helicopter	SCAT	9,096	715	1,030
	Utility	9,747	0	1,530
Compound Helicopter	SCAT	10,441	773	1,030
	Utility	10,962	0	1,530
ABC	SCAT	10,292	713	1,030
	Utility	10,954	0	1,530
Compound ABC	SCAT	11,182	795	1,030
	Utility	11,838	0	1,530
TR	SCAT	10,850	653	1,030
	Utility	11,371	0	1,530

Figure N-4. Baseline designs.

b. Findings.

(1) A SCAT designed to 500 fpm VROC at 6,000 ft at .95 IRP results in a Utility fallout with a HOGE payload capability of five troops for a lower penalty in weight and cost than designing a balanced SCAT and Utility at 5,000 ft, .90 IRP and operating at 6,000 ft, .95 IRP.

(2) For an additional .5 to 2.0 percent increase (depending on configuration) in gross weight and .25 to 2.5 percent increase (depending on configuration) in cost, full Utility payload capability can be achieved at 6,000 ft, i.e., six troops.

(3) Designing to 8,000 ft/95°F results in increases in weight and cost generally greater than 10 percent above designs based on 4,000 ft/95°F.

(4) The UTTAS and Army Helicopter Improvement Program (AHIP) COEA reports substantiated the need to design to 6,000 ft/95°F.

(5) If the engine size is fixed, the helicopter gives the best altitude-vertical flight capability combination for the investment.

c. Conclusions.

(1) It is possible to develop a SCAT with a 500 fpm VROC at 6,000 ft/95°F for a 4-5 percent increase in mission gross weight over a design at 4,000 ft. The increase in unit flyaway costs would range from 2 to 4 percent. The fallout Utility would have a payload of approximately five troops and two Stinger air-to-air missiles. The increase in the Utility mission gross weight is approximately 1 to 4 percent with an associated unit flyaway cost of between 2 and 5 percent. The ranges are configuration-driven.

(2) For a 4-6 percent increase in weight and 3-5 percent increase in cost, full capability for both the SCAT and Utility at 6,000 ft/95°F can be obtained.

(3) For a fixed engine size, the helicopter delivers a better altitude-vertical flight capability combination than any of the other designs.

(4) The helicopter is the lowest cost system to achieve increased altitude-vertical flight capability.

N-5. MANEUVERABILITY/AGILITY (M/A) ANALYSIS.

a. Purpose. To investigate the differences in maneuverability/agility (M/A) characteristics among the different configurations.

b. Background. An intent of the LHX program is to develop a "highly" maneuverable/agile rotorcraft which would enhance mission effectiveness through the synergistic effect of flight characteristics and expected increased survivability.

c. Methodology. Maneuverability in this analysis is defined as the capability to change the flight path of the system in a controlled manner. Agility is defined as the rapidity with which the change to flight path command is affected. The maneuverability parameters include rate of climb, rate of descent, and turn radius. The agility parameters include longitudinal acceleration, longitudinal deceleration, and turn rate. All parameter comparisons are based on steady state or sustained levels. The reason for this

is the fact that M/A requirements in the combat environment for the LHX have not been postulated beyond the desired need for a ". . . . highly maneuverable and agile rotorcraft" to replace the aging UH-1, AH-1, and OH-58 type aircraft. As the LHX program progresses into the COEA phase, perhaps the requirements will be more specifically defined. A quantitative ranking scheme is used to determine which design(s) are preferred. The scheme is presented in section N-V-5 of annex N-V. This analysis does not attempt to integrate the synergism of other aircraft characteristics in determining which design is preferred. The analysis is based on the information provided by the TOD. The paragraphs below state the results of analyzing the 4,000'/95°F SCAT design variants. Similar results are obtained in annex N-V for the utility design and for both designs at 2,000'/70°F.

(1) Longitudinal acceleration. Longitudinal acceleration capability is considered to be vitally important in the speed range for best endurance which is the loiter speed band and at which specific excess power potential is maximized, which translates to improved chances of evading or engaging a threat. Inspection of the data shows that in the 0-40 kt region the helicopter would be preferred over the advancing blade concept (ABC) as it is consistent. The other three designs would rank equally behind the helicopter and ABC. In the 40-120 kt interval, the order of preference would be tilt rotor (TR), helicopter, ABC, and compound helicopter designs, equally. Above 120 kt, the ranking would be TR, compound ABC, helicopter/ABC, and compound helicopter. Helicopter/ABC means both are equal in ranking. On the basis of the information, the conclusions are that the helicopter is the preferred system in the 0-40 kt interval and that the TR is preferred above 40 kt. In overall perspective, the TR would be the preferred system because at the best endurance speed of the helicopter, the TR would be 30 to 40 percent better than the helicopter and, as stated above, this would provide an inherent survivability advantage. Other aspects such as aircraft signature, aircraft survivability equipment (ASE) suite effectiveness, vulnerability, and armament, etc., are not included.

(2) Longitudinal deceleration. A review of the data shows the compound ABC and compound helicopter to have substantially better deceleration characteristics over the complete speed band, followed by the ABC, helicopter, and TR, respectively. Deceleration is similar to acceleration relative to survivability potential in that the greater the capability the greater the inherent potential for survivability given that deceleration is the tactic of the moment. The advantage of the compound ABC and compound helicopter is prominent at the higher end of the speed band where deceleration is an essential performance characteristic relative to masking to evade threat systems. On the basis of this data, the preferred systems would be the compound ABC and the compound helicopter, followed by the ABC, helicopter, and TR, respectively.

(3) Turn rate agility. The data shows the helicopter to clearly be the preferred system from 0-120 kt. However, beyond 100 kt the helicopter becomes the least preferred. Above 100 kt, the preferred system is the TR, followed by the compound helicopter, compound ABC, ABC, and helicopter.

(4) Turn radius maneuver. Partioning the speed band into three intervals shows that in the 0-40 kts interval, the order of preference is helicopter, compound helicopter/ABC, compound ABC, and TR. In the +40-120 kt region, the preferred system would remain the helicopter, followed by the compound helicopter, ABC, compound ABC, then the TR. Above 120 kt, the order would be TR, compound helicopter, compound ABC, and helicopter.

(5) Climb maneuver. The data indicates that the order of preference would be TR, compound helicopter, then helicopter, ABC, and compound ABC in the 0-40 kt interval. In the +40-120 kt interval, the ordering would change to compound helicopter, compound ABC, helicopter/ABC, then TR. Above 120 kt, the ordering would be TR, compound helicopter/compound ABC, then helicopter/ABC.

(6) Specific excess power. Specific excess power (Ps) is a measure of the relative capability of different designs to change energy state as related to air combat maneuvers. In air combat, the maneuvering advantage will go to the aircraft that can enter an engagement at a higher energy level and maintain more energy than his opponent, or enters the engagement at a lower energy level but can gain energy quicker than his opponent. The energy level is expressed by an aircraft's capability to change altitude relative to time (dhe/dt). This definition is synonomous with rate of climb and for a first order approach; comparison of this data can be used to indicate which aircraft have the advantage. A review of the speed-power polars for each aircraft shows the helicopters to be grouped in the 80-110 kt interval for which Ps would be maximized and that the TR is maximized in the 130-150 kt interval. The selection as to which speed band is more desirable would be based on the specific mission being carried out and is left to the LHX-COEA for resolution.

(7) Rate of descent maneuver. High rates of descent are not necessarily desirable within the altitude band in which the LHX will be operating. However, the ability to descend in a controlled, rapid manner is essential in minimizing the threat. The comparisons presented are based on the "best attainable" and ignores operating altitude. On this basis, the data shows that the 0-40 kt ranking would be compound helicopter, ABC, compound ABC, and TR, followed by the helicopter. In the +40-120 kt region, the ranking is the same. However, above 120 kt, the ordering changes to TR, ABC, compound ABC, helicopter, and compound helicopter.

(8) Ranking. In order to determine a preferred system, a number ranking technique is used to establish (if possible) the preferred system in each speed interval previously discussed. Since there are five designs, values of 1 through 5 are used with the low values being the preferred value. However, if two aircraft are essentially equal, the two values are added, divided by 2, and the results given to each configuration. The results are tabulated in figure N-5. From figure N-5, it is noted that the helicopter and compound helicopter are the preferred systems for the first two speed intervals and that the TR is the preferred system above 120 kt.

	0-40 Kt					+40-120 Kt					Above 120 Kt				
	HEL*	HEL-C*	ABC	ABC-C*	TR	HEL	HEL-C	ABC	ABC-C	TR	HEL	HEL-C	ABC	ABC-C	TR
Long Acceleration	1	4	2	4	4	2	4.5	3	4.5	1	3.5	5.0	3.5	2	1
Long Deceleration	2.5	1.5	2.5	1.5	5	4	2	3	1.0	5.0	4	2	3	1	5
Turn Rate	1	3.5	3.5	3.5	3.5	1	3.5	3.5	3.5	3.5	5	2	4	3	1
Turn Radius	1	2.5	2.5	4	5	1	3	3	3	5	4.5	2.5	4.5	3	1
Climb Rate	4	2	4	4	1	3.5	1	3.5	2	5	4.5	2.5	4.5	2.5	1
Descent	5	1	3	3	3	5	1	3	3	3	4	5	2.5	2.5	1
Raw Score	4.5	14.5	17.5	20.0	21.5	16.5	15	19	17	22.5	26	18.5	21.5	14	10
Normalized to Helicopter	1.0	1.0	.83	.73	.67	1.0	1.10	.87	.97	.73	1.0	1.41	1.21	1.86	2.60

*HEL - helicopter
HEL-C - compound helicopter
ABC-C - compound ABC

Figure N-5. M/A scores of LHX-SCAT candidates, 4,000'/95°F.

(9) Maneuverability/agility - quality index. In a further effort to identify a clearly preferred system, a M/A quality index is offered which uses the scores from figure N-5. In addition, the unit cost and design gross weight are presented for each speed interval for each candidate. This technique is outlined below:

$$\text{M/A Quality Index} = \frac{\text{PD HEL}}{\text{PD X}} \times \frac{\text{Cost HEL}}{\text{Cost X}} \times \frac{\text{Weight (Wt) HEL}}{\text{Wt X}}$$

where: PD HEL = Ranking score of preliminary design helicopter (figure N-5)

PD X = Ranking score of preliminary design of other rotorcraft (figure N-5)

Cost HEL = Unit cost ($M) of PD helicopter (per 1,000 units)

Cost X = Unit cost ($M) of other PD rotorcraft (per 1,000 units)

Wt HEL = Helicopter design gross weight

Wt X = Rotorcraft design gross weight

PD HEL M/A quality index = 1.00

Index values >1.00 indicate system is preferred relative to helicopter

Results obtained using this technique are listed in figure N-6.

	0-40 Kt	+40-120 Kt	Above 120 Kt
Helicopter	*1.00	*1.00	1.00
Compound Helicopter	.81	.89	1.14
ABC	.68	.716	0.996
Compound ABC	.525	.703	1.345
TR	.516	.561	*1.989

*Best value within the given speed range.

Figure N-6. M/A quality index, LHX-SCAT, 4,000'/95°F.

The filtration analysis to this point shows the helicopter to be the preferred system up to 120 kt. Above 120 kt, the ranking is TR, compound ABC, compound helicopter, helicopter, and ABC. However, because of the TR high index value, it would be the only preferred system. At this point in the analysis another aspect needs to be introduced in order to identify a "preferred" system. The additional consideration is the amount of time that speed (low/high) is utilized based on mission profiles. The percentage of time per mission that the rotorcraft would be operating above 100 kt is shown in figure N-7. Percentages are based on flying the missions with the helicopter. From figure N-7, it is observed that 9 of the 12 missions (75 percent) have flight segments that result in the rotorcraft flying above 100 kt for 65 percent, or greater, of the total mission time. This analysis concludes that although a majority of the SCAT missions in the Middle East (and Europe) are flown in excess of 100 kt, the critical part of the mission is that portion where the rotorcraft must operate at low speed in and out of confined areas and where M/A is prerequisite to mission success; therefore, the helicopter is the overall (speed/range) preferred system.

Mission	Mission Definition	Percent Time V > 100 Knots
12	Antiarmor	66.7
13	Antipersonnel/materiel	84.3
14	Special operations forces (SOF) strike	95.7
15	Reconnaissance	58.8
16	Security	24.8
17	Deep strike	87.4
18	Rear area combat operations	66.7
19	Suppression of enemy air defense (SEAD)	65.0
20	Amphibious assault	78.1
25	Air-to-air	65
26	Offensive air	65
45	Nuclear, biological, and chemical (NBC) survey	27.9

Figure N-7. SCAT helicopter; percent time above 100 kt, Middle East, 4,000'/95°F.

d. Findings/Conclusions.

(1) Findings.

(a) The helicopter is the preferred system in the 0-40 kt true airspeed (KTAS) and 40-120 KTAS interval.

(b) The TR is the preferred system in the above 120 KTAS interval.

(c) Considering the level of technology of the rotorcraft designs, it may be that all systems possess acceptable levels of M/A.

(2) Conclusions.

(a) The opportunity to capitalize on and develop new technology suggests that both a helicopter and a tilt rotor should be selected for competitive flight tests so as to establish low speed (0-120 KTAS) flight dynamics comparisons.

(b) If a dissimilar fly-off is not permissible, then the helicopter would be the general overall preferred system considering criticality of terminal area operations (low speed, confined areas) because of the helicopter's vertical flight and handling quality characteristics, plus the weight growth margin and cost.

N-6. LEVEL FLIGHT ANALYSIS-SPEED.

a. Purpose. This section of the level flight analysis will examine the inherent speed capabilities of each LHX candidate relative to each other and how these speed differences impact on productivity. A central issue of the LHX is the need for speed. The merits of speed in the overall context of mission productivity, survivability, and deployability will be determined on the basis of results obtained from computer simulations of mission profiles with threat overlays.

b. Findings/Conclusions.

(1) Findings.

(a) The TR speeds are significantly higher than the other LHX configurations.

(b) The TR has a large best endurance airspeed (V(BE)) interval because of its ability to alter/modify the configuration shape through nacelle/rotor incidence management.

(c) For the intervals analyzed, the TR transforms horsepower into speed more efficiently than the other configurations.

(d) The results of the helicopter mission survivability model (HELMS) analysis show that the various aircraft configurations possess sufficient performance capabilities to negotiate the flight routes while utilizing approximately 70 percent of their maximum speed capability. The mission completion times only increase 1 to 3 percent for the lower altitude band, indicating the configurations are capable of high speed flight at altitudes of lower than 25 ft while suffering only very minor degradations in mission time and distance with only slight decreases in exposure time.

(e) The TR experiences significant advantages in mission time over the remaining configurations. By combining all missions for both SCAT and Utility, the TR has a 38 percent advantage over the helicopter, a 35 percent advantage over the ABC, a 29 percent advantage over the helicopter-compound, and a 28 percent advantage over the ABC-compound. Other than the TR, only the ABC-compound has a greater than 10 percent advantage over the helicopter (13 percent).

(f) The mission profile prioritization Delphi process provided the mission frequencies for each mission. When these statistics were combined with the mission times and summed over all missions, similar results were obtained. This statistic weights the mission times to provide a more realistic view of the advantage of speed and results in a significant advantage for the TR with the other configurations close to the helicopter.

(g) The analysis of variance (ANOVA) results show that the only statistically significant difference in mission completion time was between the TR and helicopter; the remaining configurations had times which were very close and thus were not significant. While there was a significant difference in mission time for the TR, there was no significant difference among configurations for exposure times. The exposure times were virtually equal except for the derivative A129 SCAT and S175 Utility. This is significant in that the TR increases productivity approximately 35-40 percent while suffering no increase in exposure time. The ANOVA also provided data that showed there was no appreciable difference in mission statistics between the two altitude bands, 0-25 ft and 0-150 ft. This is evidence that contradicts the addage "the faster you go, the higher you fly." The HELMS results show that as airspeed increases, flight altitude also increases but levels off around 20-30 ft above ground level. It is important to note that the HELMS results do not consider the human capability but only represent the aircraft's capability. It is presumed the altitudes would increase slightly if a human's tolerances were considered.

(2) Conclusions.

(a) The only significant productivity gains occur with the TR configuration. These gains are based on the TOD designs with the MEP performance outlined in appendix O.

(b) Based on performance characteristics, the TOD designs are capable of high speed flight at altitudes at or below 25 ft.

(c) The combination of improved MEP and TR performance provide a substantial productivity and survivability enhancement over the TOD designs analyzed during the trade-off analysis.

N-7. LEVEL FLIGHT ANALYSIS-CRUISE EFFICIENCY.

a. Purpose. This section of the level flight analysis will examine the cruise efficiencies of each candidate system relative to power required and fuel flow. The analysis addresses SCAT and Utility candidates based on new rotorcraft designs. The new designs include a helicopter, compound helicopter, ABC, compound ABC, and a TR. The conditions to be examined are 4,000 ft/95°F and 2,000 ft/70°F. Comparisons will be at the design gross weight value.

b. Findings. The data presented in annex N-VII is summarized in figures N-8 and N-9 relative to differential unit cost and indicates the following:

(1) All configurations are less efficient than the helicopter relative to power, fuel flow, and cost.

(2) In all cases, the compound ABC SCAT and Utility configurations are outliers and are indicative of either poor configurations relative to LHX requirements or an insufficient data base used in developing the designs.

(3) The compound helicopter is the more efficient design.

c. Conclusions.

(1) The compound ABC should be dropped from consideration.

(2) The ABC and compound helicopter should be dropped from consideration because they afford approximately the same speed potential as the helicopter but at a penalty in power, fuel consumption, and cost.

(3) The TR should be retained for consideration until the wide margin in speed capability is thoroughly explored.

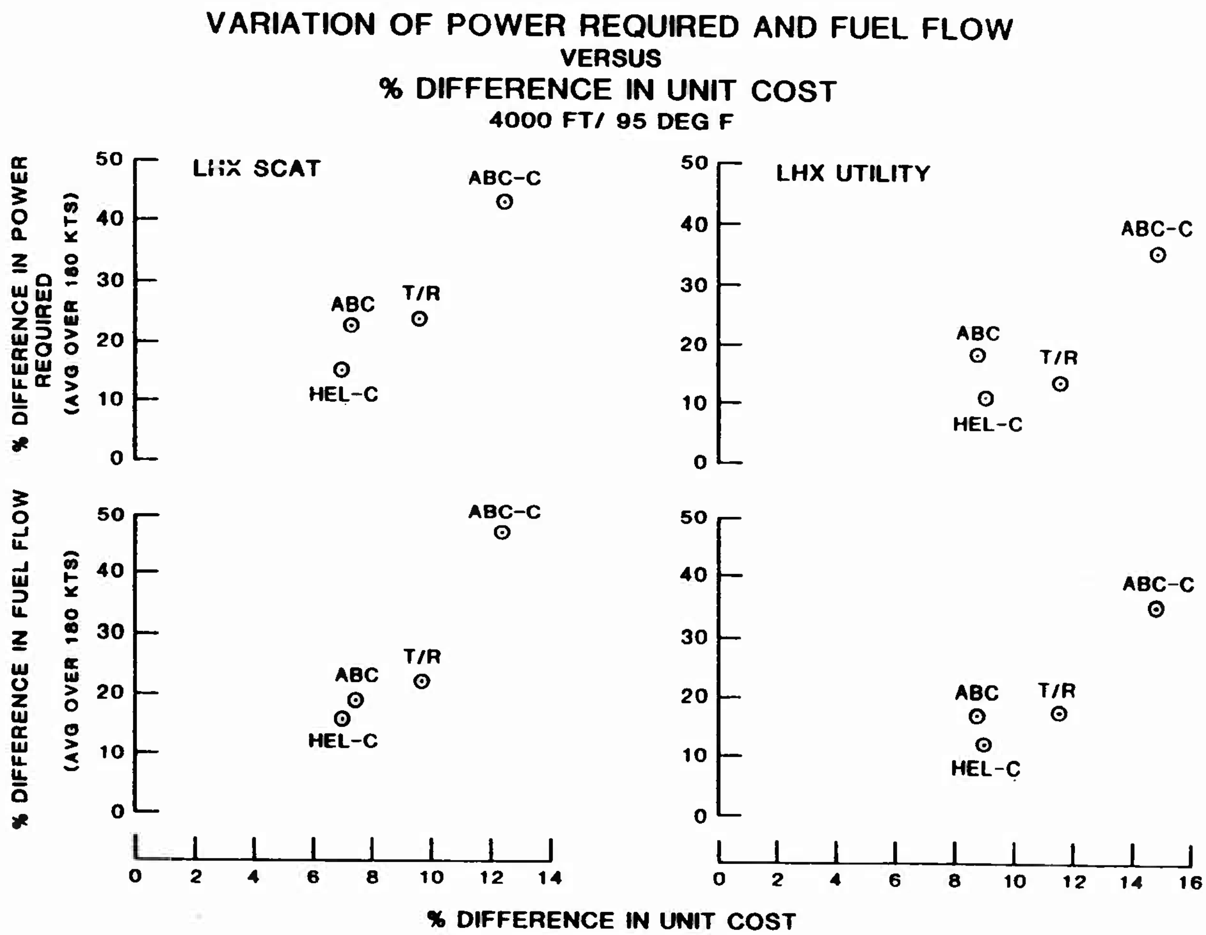

Figure N-8. Power required and fuel flow summary: 4,000'/95°F.

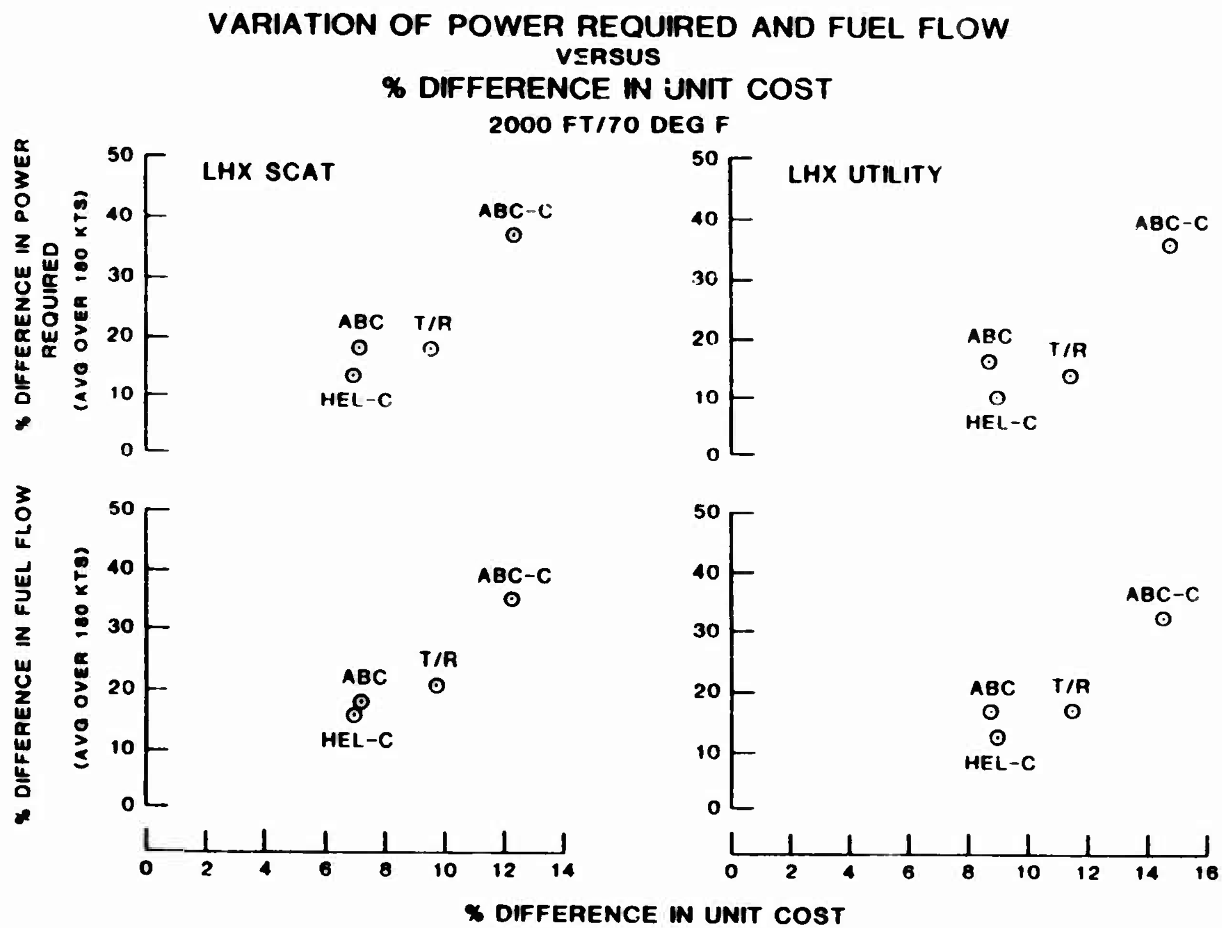

Figure N-9. Power required and fuel flow summary: 2,000'/70°F.

N-8. LEVEL FLIGHT ANALYSIS-ONE ENGINE INOPERATIVE (OEI).

a. Purpose. This section of the level flight analysis will examine the single-engine operational constraints regarding the ability of the LHX candidate to maintain en route capability.

(1) This section will address SCAT and Utility candidates of new design rotorcraft.

(2) The condition to be examined is 4,000 ft/95°F.

(3) Comparisons will be made at the design gross weight value.

b. Methodology. The methodology consists of determining the interval, if any, at which each candidate can maintain level flight. The intent is to determine if any specific candidate has a distinct advantage. In addition, an assessment is made as to the merits of an emergency rating for the engine. In addition, an evaluation is made to determine if the LHX can transition from level flight to a hover in ground effect (HIGE) condition to effect a landing. The level of offloading necessary to effect the transition/landing is presented.

c. Findings. SCAT and Utility summary charts are presented in figures N-10 and N-11.

(1) 4,000 ft/95°F.

(a) SCAT.

1. All designs have en route single-engine capability.

2. All configurations would have to off-load payload and/or fuel to perform a vertical landing.

3. The TR and compound helicopter have the widest speed range with the compound helicopter having the lowest speed point and the TR having the highest speed point.

4. The TR high speed interval is attained in the FW mode. In the helicopter mode, the upper limit is approximately 100 kt versus 181 kt.

5. The rank order by inspection of the designs is:

a. TR and compound helicopter. (NOTE: The TR and compound helicopter rank equally.)

b. Helicopter.

c. ABC.

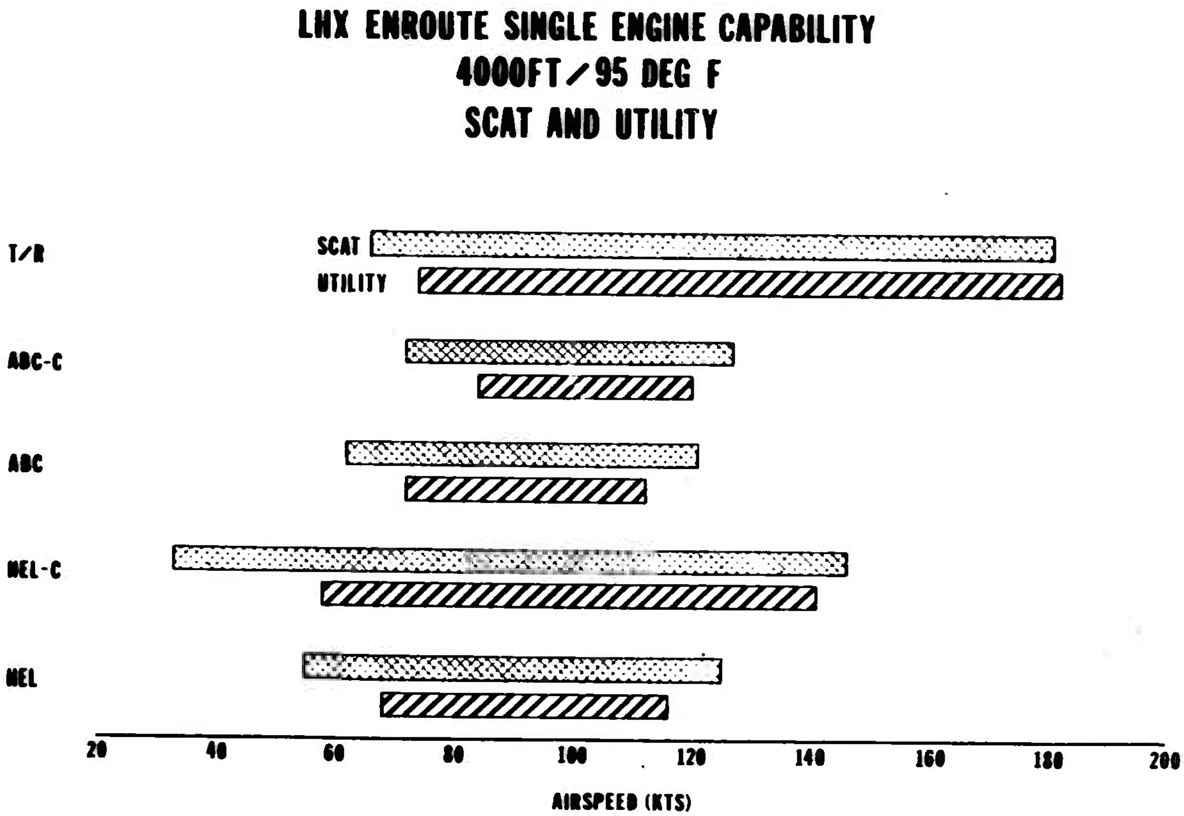

Figure N-10. SCAT and utility OEI summary, 4,000'/95°F.

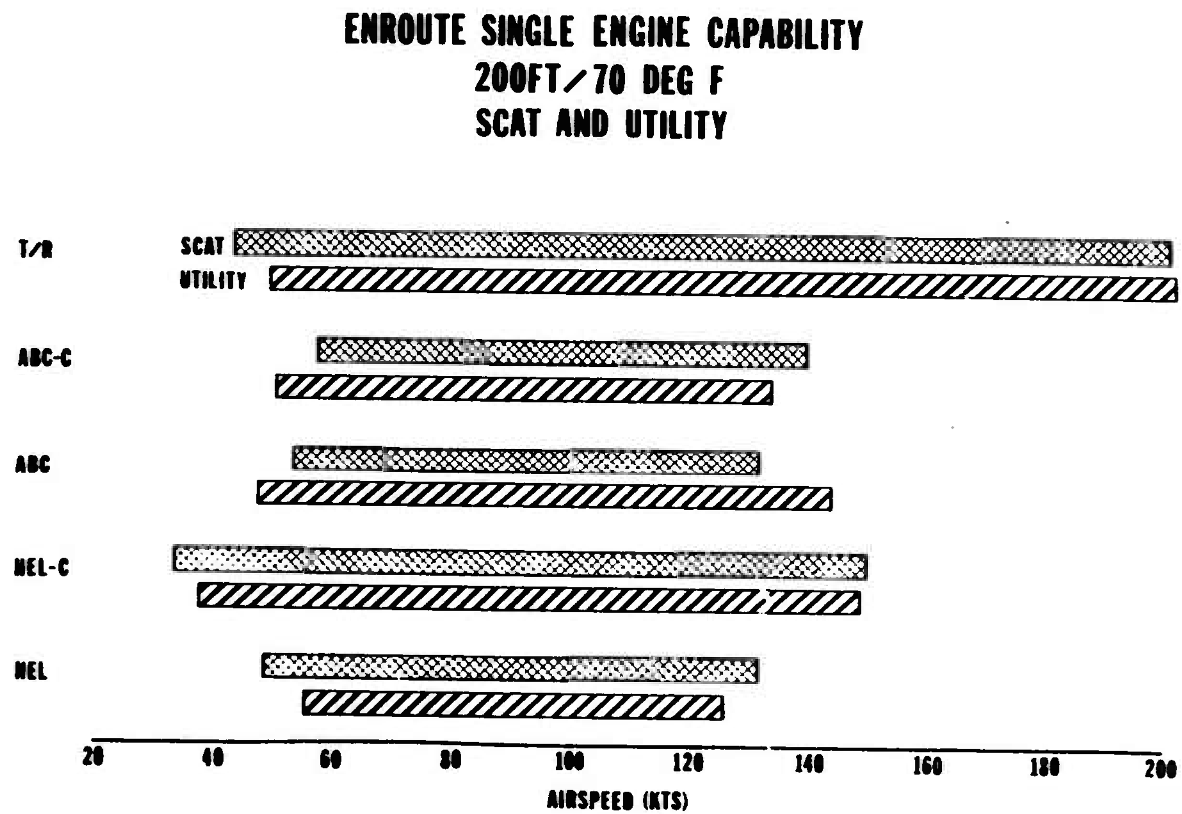

Figure N-11. SCAT and utility OEI summary, 2,000'/70°F.

d. Compound ABC.

(b) Utility.

1. All designs have en route single-engine capability.

2. All configurations would have to off-load payload and/or fuel to perform a vertical landing.

3. The TR and compound helicopter have the widest speed range with the compound helicopter having the lowest speed point and the TR having the highest speed point.

4. The TR high speed interval is attained in the FW mode. In the helicopter mode, the upper limit is approximately 100 kt versus 182 kt.

5. The rank order by inspection of the designs is:

a. TR and compound helicopter. (NOTE: The TR and compound helicopter rank equally.)

b. Helicopter.

c. ABC.

d. Compound ABC.

(2) 2,000 ft/70°F.

(a) SCAT.

1. All designs have en route single-engine capability.

2. All configurations would have to off-load payload and/or fuel to perform a vertical landing.

3. The TR has a substantially larger speed interval by using pylon tilt variability.

4. The rank order by inspection of the designs is:

a. TR.

b. Compound helicopter.

c. Helicopter, ABC, compound ABC. (NOTE: The helicopter, ABC, and compound ABC rank equally.)

7d

(b) Utility.

1. All designs have en route single-engine capability.

2. All configurations would have to off-load payload and/or fuel to perform a vertical landing.

3. The TR has a substantially larger speed interval by using pylon tilt variability.

4. The rank order by inspection of the designs is:

a. TR.

b. Compound helicopter.

c. Helicopter, ABC, compound ABC. (NOTE: The helicopter, ABC, and compound ABC rank equally.)

(3) Overall. The TR appears to provide the best overall OEI capability, followed by the compound helicopter, helicopter, ABC, and compound ABC.

N-9. MULTIPLE ATTRIBUTE DECISION MAKING (MADM) ANALYSIS.

a. Purpose. A multiple attribute decision making (MADM) analysis was performed to determine if, on the basis of selected parameters, one of the LHX configurations presented in the TOD would clearly be a preferred design.

b. Findings.

(1) Based on a broad range of characteristic parameters, each of equal weight, the helicopter-compound is the highest value system, followed in order by the helicopter, the ABC, the ABC-compound, and the tilt rotor.

(2) Varying the relative weights of the parameters significantly changes the outcome.

c. Conclusions.

(1) The helicopter-compound is the preferred system based on the method used and the associated parameters.

(2) Further effort should be directed toward perfecting the MADM technique to provide the insights to the benefits of the candidate designs.

N-10. AIRCRAFT PERFORMANCE AND ENGINE POWER MARGIN.

a. Purpose. The purpose of this substudy is to analyze the impact of providing the LHX with an engine that incorporates a built-in power margin.

b. Background.

(1) Gas turbine engines for Army aircraft have been required to grow subsequent to fielding (figure N-12) as a result of aircraft system growth (weight increases) and changes in requirements. Periodic growth in engine power has resulted in time lags and high cost penalties (AMC cost data indicate that a $1 design change made subsequent to production will cost the Army $1,000 to implement).[1]

(2) Army helicopters typically experience empty weight increases on the order of 1-3 percent per year because of design changes, new equipment installation, and field repairs. The UH-60A (Black Hawk) has experienced an average empty weight increase of approximately 1 pound (lb) per production aircraft since it was fielded in 1979. Figure N-13 shows the actual empty weight (lb) increases and the trend which apparently has been established.

(3) Changes in mission payload requirements and operational capabilities have historically been required, resulting in gross weight increases of the system. Figure N-14 depicts the variation of helicopter design gross weight and installed power with design altitude. A change in the design altitude criteria from 4,000 feet to 6,000 feet results in a gross weight increase of approximately 450 lb and a corresponding increase of 160 horsepower. Figure N-15 shows the increase in gross weight the Black Hawk has experienced due to the addition of blade deice and external stores support system (ESSS) and the projected gross weight increases due to the hover infrared suppressor system (HIRSS) and improved main gear box (MGB). Also shown on figure N-15 is the current maximum takeoff gross weight (TOGW) of the T700-700 and T700-700/+5-percent engines. Additional changes in the operational capability of the Black Hawk currently being defined in the required operational capability (ROC) for the Black Hawk Improvement Program will substantially increase the gross weight, causing an additional increase in power required. A 6-year engine development program costing approximately $120M will be required to provide this additional power.

c. Findings. While the weight and cost impact of providing an engine with power margin is significant, the potential gains in improved mission performance capability and system growth potential appear to warrant developing an engine with a built-in power margin.

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1. Annex 1, Appendix O, Volume IV, Advanced Scout Helicopter (AHS) Special Study Group Final Report, December 1979.

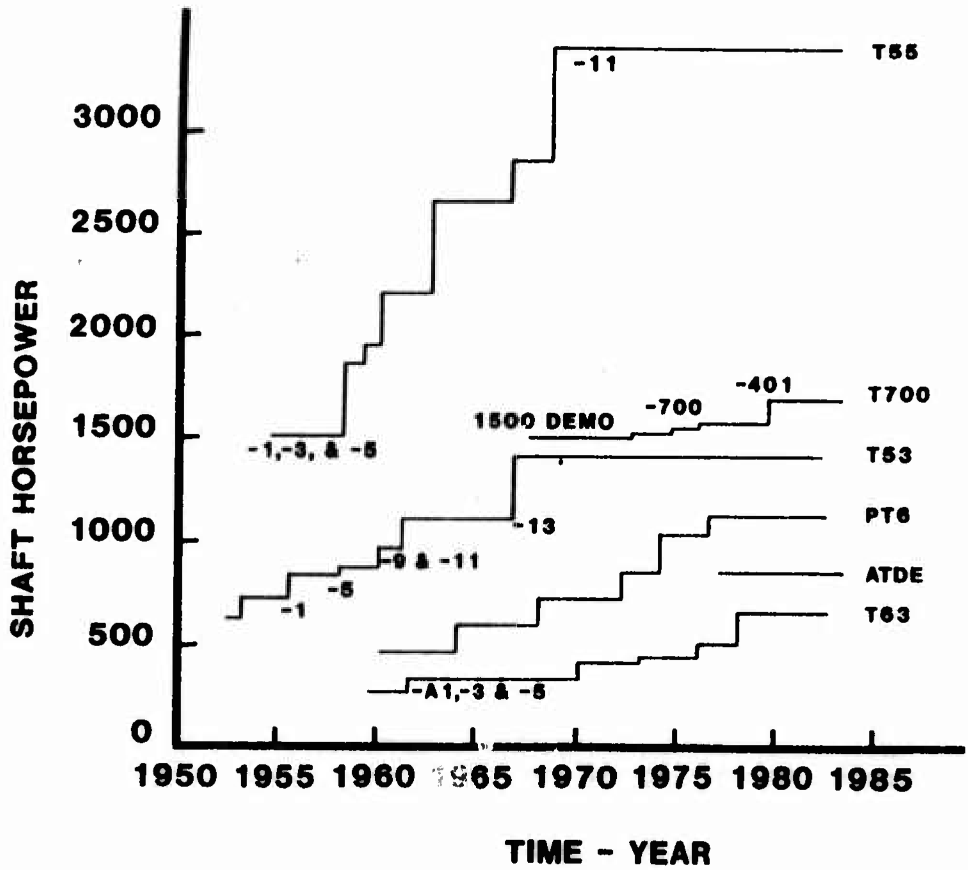

Figure N-12. Turbine engine growth history.

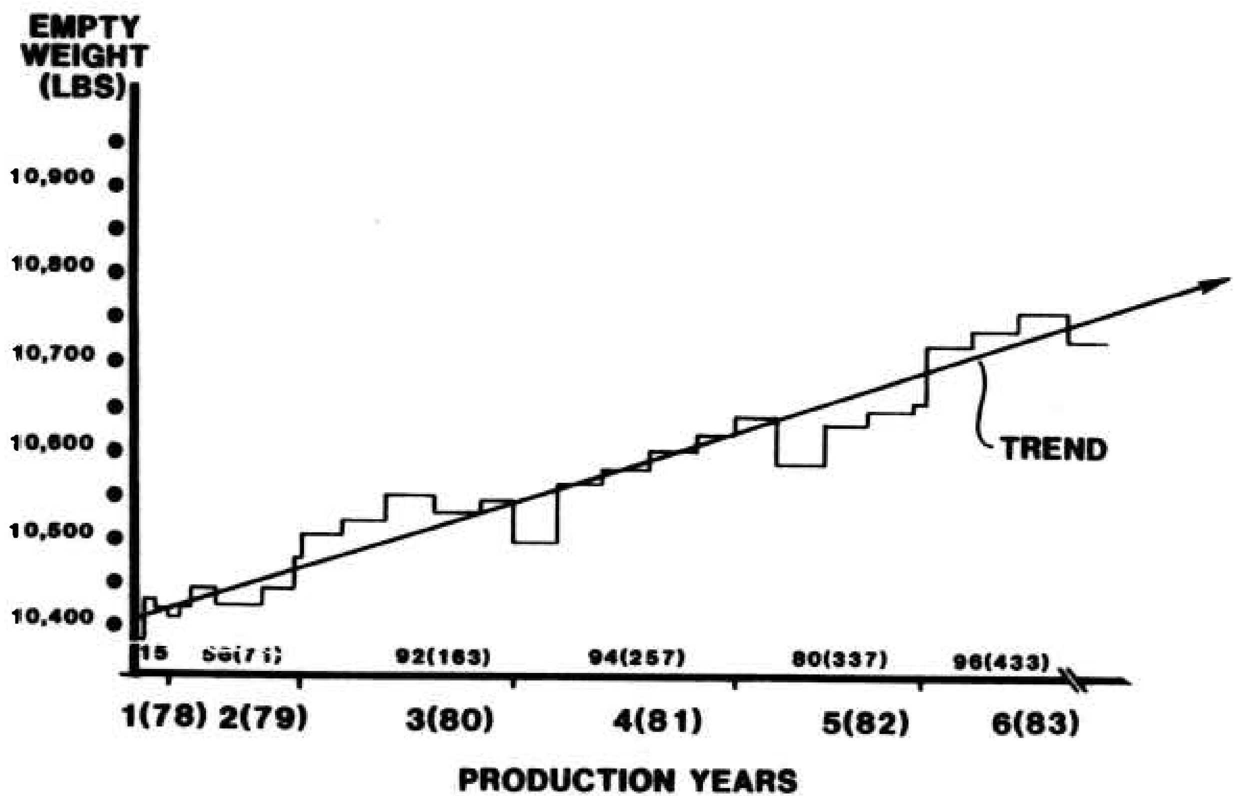

Figure N-13. UH-60 weight growth.

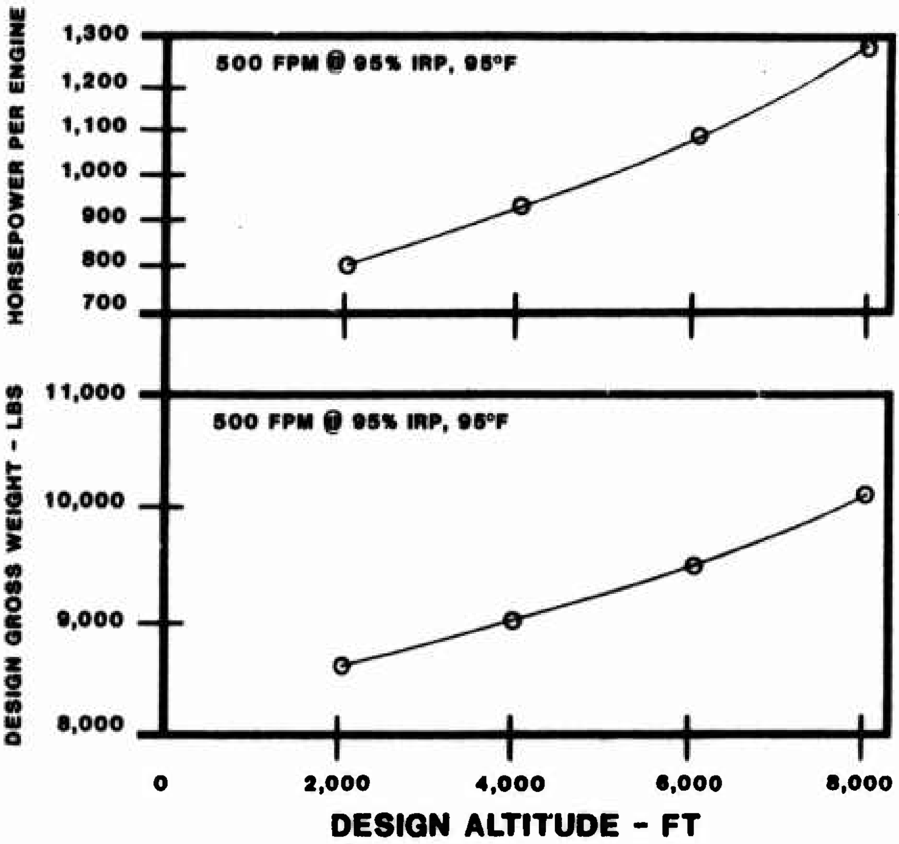

Figure N-14. Variation of helicopter gross weight and installed power with design altitude.

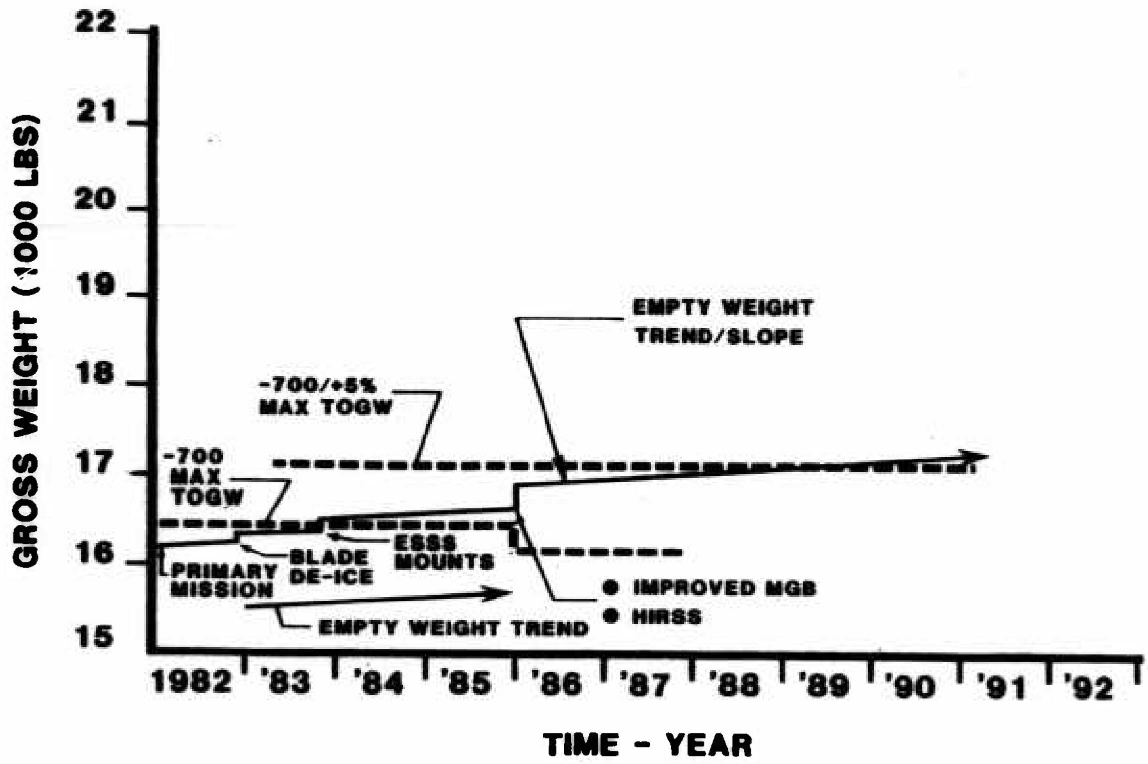

Figure N-15. UH-60 gross weight increase.

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ANNEX I TO APPENDIX N

LIGHT HELICOPTER FAMILY (LHX) SUBSYSTEMS (U)

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ANNEX I TO APPENDIX N

LIGHT HELICOPTER FAMILY (LHX) SUBSYSTEMS (U)

N-I-1. (U) INTRODUCTION.

a. (U) The following subsystems are addressed in this section of the TOA report: onboard power sources (electrical, pneumatic, and hydraulic); an environmental control system (ECS); an onboard oxygen generating system (OBOGS); an anti-icing/deicing system; a standard flight data recorder (SFDR); an onboard refueling system; a fire detection, warning, and extinguishing (FDWE) system; and cargo-handling and rescue hoist provisions.

b. (U) The pertinent issues and trade-offs are shown so that the desired/ required subsystem characteristics can be established for the baseline LHX configurations and their variants. Only significant subsystem differences are addressed. Because maximum commonality in the subsystems is desired, the subsystems described apply to LHX candidate configurations and to both the LHX-Scout/Attack (SCAT) and LHX-Utility versions.

N-I-2. (U) ONBOARD POWER SOURCES.

a. (U) Electrical Subsystem.

(1) (U) The electrical subsystem consists of power-generating devices, power controls, and circuit controls necessary to sustain the mission equipment package (MEP), weapons, anti-icing/deicing, lighting, and other general aircraft electrical loads. The pertinent issues that are addressed in this section include the following:

(a) (U) Battery versus auxiliary power unit (APU) as power source for engine start and electronics checkout.

(b) (U) Icing protection with regard to electric power sizing.

(2) (U) In arriving at the selected electrical system power requirement, inputs from the MEP and weapon analyses were assessed. The baseline/ variant LHX will require anti-icing/deicing protection in addition to normal electrical loads. These requirements have been established as 10 kilovolt-ampere (KVA) and 9.9 KVA, respectively. The 10-KVA load is applied only during adverse (icing) conditions, whereas the 9.9-KVA electrical load is a normal continuous load. The MEP has defined a continuous load of 18.35 KVA for the two-man tandem SCAT. Weapons maximum load has been established as 14.0 KVA.

(3) (U) Since the user desires an ability to rapidly check out the MEP and weapons prior to flight and requires a power source for maintenance actions, a battery-versusAPU issue arose. The high load of the MEP would rapidly deplete battery reserves, especially if anti-icing is required for the

visionics. This would make electrical main engine start tenuous, particularly during cold weather operations. Based on this comparison (see figure N-I-1), the APU has the operational advantage.

APU		Battery	
Advantages	Disadvantages	Advantages	Disadvantages
ECS operates on ground without rotor turning Small battery (16.8 pounds (lb)) Battery only for APU ignition and flight control backup Low-weight engine starter (10 lb) Perform maintenance and system checkout for long periods Improved aircraft dispatch reliability MEP can be powered up in holding areas UNCLASSIFIED	Added weight of shaft-driven compressor (SDC) (55 lb) High-cost APU	Simpler system Low-cost battery	Environmental control unit only operates with engine running Bleed air creates engine performance penalty Heavy battery with heater (100+ lb) Heavy electrical engine starter (23 lb) Large/heavy charging and monitoring system for battery Battery failure has severe safety impact

Figure N-I-1. (U) APU-versus-battery summary.

(4) (U) Electromagnetic interference/electromagnetic pulse protection for the electrical system has been examined. Extensive shielding of wiring is necessary. In addition, methods for maintaining protection following repair are currently being addressed by Applied Technologies Laboratory, and repair procedures, tools, and equipment will be on hand for LHX full-scale engineering development.

(5) (U) Conventional circuit breakers will be used to the maximum extent possible for the normal electrical requirements. Computer-controlled remote control circuit breakers will be used on the power management system. These will be required to handle the rapid load shedding necessary in case of a generator failure.

(6) (U) The total electrical subsystem weight for the baseline LHX is computed at 318 lb. The LHX wiring weight is estimated to be 60 lb, which is the current AH-64A wiring weight. The wiring weight of the smaller LHX compensates for the 100-percent increase in MEP power and the wiring shielding requirement.

(7) (U) The electrical subsystem design is completely dependent upon the MEP, weapon system, and anti-icing/deicing requirements. The subsystem has to be designed to handle the maximum continuous power, as well as the peak power loads of the above systems, even though the rotor deicing capability may be provided in kit form.

b. (U) Pneumatic Subsystem.

(1) (U) The pneumatic subsystem for the five LHX baseline configurations, each with a SCAT, a utility, and a variant from the baselines, consists of the ECS, the main engines starting system, OBOGS, the nitrogen inerting unit (NIU), the anti-icing/deicing system, and the APU. The purpose of the pneumatic subsystem is to provide cooled air to the cockpit and avionics bay, cooled air to the crew protective clothing, overpressure for the cockpit and avionics bay, heated air for the cockpit and cabin of the utility variant, heated air for anti-icing of engine inlets, high-pressure air for main engine starting, and high-pressure air for the NIU/OBOGS. Pneumatic power can be obtained through main engine bleed or from a separate compressor. Engine bleed, however, is costly in terms of the engine performance penalty.

(2) (U) Because of this severe performance penalty, pneumatic power for the LHX-SCAT and Utility configurations was selected to be supplied from an SDC. This compressor is driven through the accessory gear box (AGB) by the transmission during flight or the APU while the aircraft is on the ground. In addition, the APU will be able to drive the compressor, generators, and hydraulic pumps during flight in an emergency situation.

(3) (U) The APU was selected to provide electrical power for the MEP, weapons, and subsystem checkout; hydraulic power for the flight control and utility system; and pneumatic power for main engine starting and ECS operations. The pressurized air starting system for the main engines has a higher reliability than other starting systems and is of lower weight. Similarly, an SDC consumes less power than engine bleed air. The SDC does double duty since it serves as the compressed air source for the ECS as well as for the air turbine starter(s) to start the main engine(s).

(4) (U) Pneumatic system sizing is significantly dependent upon the crew protection required to survive in a chemical and biological (CB) environment. The current design SDC can meet the lowest protection level; however, if tandem cockpit overpressure protection is necessary following combat damage, SDC size may increase considerably.

(5) (U) The technical risk associated with the pneumatic subsystem is low. Most of the pneumatic ducting can be manufactured with composite materials in order to achieve a cost and weight savings. The only developmental items are the high-pressure CB (HPCB) filter and the NIU/OBOGS.

(6) (U) The current weight estimate (195.5 lb for the two-man SCAT) approaches 3 percent of empty weight. However, final subsystem weight could fall into 1.5 percent (100 lb) of weight empty based on the final selection of CB protection for the LHX aircraft and as a result of composite material applications.

c. (U) Hydraulic Subsystem.

(1) (U) The hydraulic subsystem for the LHX configurations consists of a primary system and a utility system. The flight controls are powered by the primary system, whereas the utility system (capable of flight control system backup) provides power for APU start, steering, braking, landing gear activation, pump for refueling, weapon elevation, azimuth positioning, and recoil control.

(2) (U) A major contributor for improved hydraulic subsystem reliability is the 5-micron filter because small particles (which cause seal and bearing failures) are continuously removed. Maintainability improvements will be experienced through modular design and by use of quick change assemblies (QCA). Fly-by-light or fly-by-wire flight control systems will also reduce the number of actuators, which will result in reliability and maintainability improvements. The five baseline configurations, each with a SCAT and Utility and variants from the baseline, will have different hydraulic systems only in terms of the number of flight control system actuators and the length of the fluid lines to these actuators.

(3) (U) Main engine starting was analyzed in terms of cost, weight, and reliability considerations and, as a result, air turbine starting for the main engines was selected. The APU, which provides the pneumatic pressure, will be started with a hydraulic starter powered by the hydraulic accumulator. Benefits in cost, weight, and reliability are realized. However, a hydraulically powered ECS was rejected due to the high power required.

(4) (U) The major concern in analyzing the total LHX subsystem was the power consumption to drive the subsystems, commonality between baseline and variant, maintenance time and skill level requirements, peacetime and wartime operation, and, of course, cost and weight considerations. In addition to the above, size in terms of power per volume was a major consideration. Because of safety considerations, the hydraulic subsystem was selected to power the onboard refuel system, as fuel fumes would be readily ignited as a result of a short in the electrical system. This system can be provided in kit form with lightweight hydraulic lines installed on the aircraft during production. An electrically powered turret was rejected because of the extensive power consumption already required by the MEP, weapon feed, and, during adverse weather, the anti-icing/deicing subsystem.

(5) (U) The candidate hydraulic configuration includes two AGB-driven pumps. These pumps will be able to supply the required flow rates and pressures even if the rotor is slowed. During ground checkout, the APU drives the AGB and hydraulic power is provided to the flight control system for centering prior to rotor startup. Similarly, weapon azimuth and elevation can be checked out during the checkout procedures.

(6) (U) Possible weight reductions associated with the use of composites for hydraulic components constitute a high risk and will not be available for LHX full-scale development (FSD). Since the hydraulic subsystem historically weighs less than 1 percent of aircraft weight empty, the cost of developing, testing, and qualifying composite components may outweigh the possible weight reduction results.

(7) (U) The recommended approach for the LHX hydraulic subsystem is the currently employed modular design, which eliminates many leaks and improves reliability and maintainability. In addition, 5-micron filtration will eliminate nearly all of the seal wear problems currently experienced. QCAs and quick-change fittings on the lines will further reduce the maintenance burden and improve reliability of this subsystem. As a result, the LHX hydraulic subsystem will be of the lowest possible weight at nominal cost and is considered to be a low-risk item. For example, retractable landing gear emergency extension will be accomplished with hydraulic blow-down from pressure being maintained in an accumulator. The accumulator size is dependent on the landing gear stroke which is design dependent. The retractable landing gear TOA in terms of weight and cost is discussed in the structures section.

N-I-3. (U) ENVIRONMENTAL CONTROL SYSTEM (ECS).

a. (U) The ECS is a module of the pneumatic subsystem of the LHX configuration. The ECS consists of an air conditioning and heating system for cooling the cockpit, crew ensemble, and avionics bay; heating the cockpit and cabin; providing filtered air for nuclear, biological, and chemical (NBC) protection; and cooling air to the NIU/OBOGS.

b. (U) The total cooling requirements, NBC protection, and heating requirements of the LHX baselines and variants were analyzed and traded against mechanical, electrical, pneumatic, and hydraulic drives for the ECS.

c. (U) The hybrid system concept for the baseline LHX was selected. This system is a combination of a filtered/cooled air overpressure system and individual CB protective ensembles with provisions for suit/facepiece cooling. In addition to facepiece cooling, the OBOGS provides oxygen to the aircrew for improved performance above 5,000 feet sea level and for improved night vision. Pressurized air enters the environmental control unit (ECU) from the SDC, which has been prefiltered to remove toxic dust above 0.3 micron and liquids. Moisture is removed in the ECU, and cooled air enters the HPCB filter. This cooled, nontoxic air is supplied to the NIU/OBOGS, the aircrew ensemble, the cockpit, and the avionics bay.

d. (U) The ECS sizing was established from inputs received from propulsion, mission equipment, and the survivability discipline. The current AH-1S ECU design uses a bleed air-driven compressor. However, the extensive power penalty associated with that design eliminated it from consideration. The AH-64A SDC design was selected as the best approach and size to meet the LHX requirements. Survivability established the cooling capacity requirement for the baseline LHX. The 16,485-British thermal units per hour or

22.0 horsepower (HP) for aircrew and cockpit cooling requirements, together with the 6.3-HP cooling requirement for the avionics bay, results in an ECS absorbing only 28.3 HP from the AGB. The selected ECS design permits maximum aircrew protection during combat, whereas during peacetime operation, when the aircrews do not wear the protective clothing, sufficient cooled air is provided for hot day operation. In addition, the OBOGS will provide oxygen as required for training or night flying. The NIU will continuously provide nitrogen to improve crashworthiness of the fuel system.

e. (U) This design will be applicable for all baseline LHX configurations and their variants. A slightly larger SDC may be necessary for the compound advancing blade concept (ABC) and tilt rotor concepts to be able to handle the same airflow during reduced revolution-per-minute operation in cruise flight. The weight increase of the SDC should be no more than 6.0 lb; that is, the weight would increase from 24 lb to 30 lb. As a result of modular design and use of QCAs, maintenance time will be kept low. The HPCB filter would not be required during peacetime and, therefore, would be designated as a QCA with a lightweight dummy casing installed in lieu of the filter. The reliability of the ECS should be high since the air particle separator will protect the SDC from erosion and the NIU/OBOGS will be supplied only cool, cleaned air. It is estimated, however, that during a CB environment or when the HPCB filter is activated it will require changing every 2 weeks, which may become a logistics burden.

f. (U) The weight of the ECS, including the SDC, gearbox, CB ensemble, and NIU/OBOGS, will be approximately 208.0 lb, of which the NIU/OBOGS module weight will only be 18.0 lb and the weight of the two aircrew ensembles will be 18.5 lb. The heaviest module of the ECS is the three-wheel boot strap ECU which will weigh 55.0 lb. Cost of the ECS hybrid system and the NIU/OBOGS module is estimated at $60,000 (fiscal year (FY) 83 dollars). Application of advanced composite materials should reduce the weight of the ECS by 10 percent; that is, the advanced composite ECS should weigh approximately 187.0 lb. The risks associated with the ECS are relatively low since only the HPCB filter and the NIU/OBOGS will require development.

g. (U) The preferred approach described above will satisfy the LHX missions. As mentioned, peacetime operation without protective garments is possible with the selected approach. Oxygen generation, as well as the cooling/heating environment, can be regulated by the aircrew. The selected system will provide a comfortable environment on the ground even during system checkout with only APU operation.

N-I-4. (U) ONBOARD OXYGEN GENERATING SYSTEM (OBOGS).

a. (U) The OBOGS is required for the LHX configuration to improve the aircrew effectiveness when operating above 5,000 feet sea level and to prevent degradation of the night vision capability. The desired features of the subsystem include light weight, low nonrecurring cost, as well as low operation and maintenance costs, and a low safety hazard.

b. (U) The pertinent issue addressed is whether the NIU could produce the quality and quantity of oxygen to satisfy the aircrew needs required to satisfy the stated LHX attributes.

c. (U) Integrating the NIU/OBOGS into the LHX ECS is the preferred alternative as it will result in an overall weight savings; it will be in-hand by FY 87; oxygen-enriched air of 40-percent oxygen minimum will be available; flow rates of 40 liters per minute minimum can be achieved; OBOGS weight for a two-man crew will be less than 18 lb; the OBOGS will provide additional CB protection for the crew; the OBOGS output will be sufficient to permit a two-man crew LHX to fly at 18,000 feet; and sufficient nitrogen will be available from the NIU section of the OBOGS to prevent fuel cell(s) fires and explosions. Additional benefits are that separate ground support equipment will not be required and also a separate military occupational specialty will not be required in order to maintain this subsystem.

N-I-5. (U) ANTI-ICING/DEICING SYSTEM.

a. (U) The worldwide deployment of the LHX underscores the need for a reliable, lightweight, effective anti-icing/deicing system. The pertinent issues addressed are icing protection with kits versus a built-in system and methods of deicing.

b. (U) Technologies to provide anti-icing/deicing functions included electrothermal, chemical freezing point depressant, bleed air, pneumatic boots, ice phobics, electroimpulse, and microwave. Candidates determined to be viable in terms of cost, weight, technology maturity, and effectiveness are electrothermal, bleed air, and pneumatic boots.

c. (U) Ice protection is generally classified as anti-icing and deicing. Anti-icing may be evaporative or running wet. In an evaporative anti-icing system, all of the impinging water is evaporated. In a running wet system, all or some of the impinging water is allowed to run back and freeze on noncritical areas.

d. (U) Deicing is presently viable either by cyclic electrothermal techniques or pneumatically inflatable boots. The areas most responsive to electrothermal techniques include the main and tail rotors. In the case of pneumatic boots, applicable areas are the wings and empennage surfaces.

e. (U) For rotors and propellers, the only viable method of protection commensurate with the LHX FSD schedule is electrothermal cyclic deicing. An electrothermal cyclic deicing system is typically composed of main and tail rotor electrothermal heating elements, main and tail rotor slip rings, a main rotor distributor, a deicing controller, an icing detector, an outside air temperature sensor, an icing rate meter, and an icing control panel.

f. (U) Engine and induction system candidate systems include electrothermal and engine compressor bleed air. Bleed air is generally preferred because of its close proximity, competitive weight, low maintainability, high reliability, and engine/airframe integration considerations.

g. (U) Windshields or forward-facing transparent areas may be protected electrothermally or by hot air ducting or freezing point depressant fluids. The electrothermal approach is composed of a transparent conductive coating and is the preferred method due to the advantages of simple ON-OFF control switch operation, the ability to obtain good control of heat distribution and temperature, the independence of system performance with respect to engine/aircraft speed, and its defogging capability.

h. (U) For flight probes, the generally accepted and simplest effective method is electrothermal.

i. (U) Weapon/target acquisition systems will require independent evaluation; however, electrothermal approaches by means of a conductive coating or wire mesh are generally the most compact and practical method.

j. (U) For the wings and empennage, the only viable method is the pneumatic boot. Electrothermal methods have not been recommended due to the fact that they would overly tax the electrical system capacity, especially in light of the mission equipment and rotor electrical requirements.

k. (U) A pneumatic boot deicing system is typically composed of deicer boots, a controller/timer, a pressure regulator, an ejector valve, a flow control valve, rotating unions, an ice detector, an icing rate meter, and an icing control panel. The air source for the system is commonly a pressure tap-on engine compressor section. These components, less the deicer boots, lend themselves to provisioning via kits.

l. (U) Estimated weight data for the baseline configurations has been tabulated in figure N-I-2. As can be seen, a weight savings of 62 to 75 lb will be realized by provisioning via kits.

m. (U) The recommended methods of protection for the various areas of the aircraft which require special provisions are presented in figure N-I-3. Of these areas, the largest penalty is imposed by the rotor system protection. The majority of rotor system icing protection components will be provisioned as kits.

N-I-6. (U) STANDARD FLIGHT DATA RECORDER (SFDR).

a. (U) The SFDR is required to provide accurate, comprehensive flight- and maintenance-related information. This information is needed for the accident investigation community to determine the cause of an accident and, additionally, to provide needed maintenance-related information to the crew and aviation unit maintenance personnel. The needed maintenance information includes that which provides engine health indications, current aircraft performance data, and historic usage data. Therefore, in addition to retaining accident-related information in a crash-survivable memory, the SFDR contains the processing capability and software logic necessary to provide to a display information to support maintenance decisions and states of subsystems. The SFDR will also support the functions of a fault detection/locator system (FD/LS). The logic of the MEP will ease the burden of the logic requirements

ANTI-ICING

Engine induction	20.0
Windshield	8.0
Pitot static	0.3
Weapons	10.0
Basic system	38.3

UNCLASSIFIED

DEICING

	Helicopter	Compound Helicopter	ABC	Compound ABC	Tilt Rotor
Main rotor blade heating elements	8.3	10.2	10.9	12.0	7.7
Tail rotor blade heating elements	0.8	0.9	0.0	0.0	0.0
Wing and tail deicer boots	0.0	20.0	0.0	0.0	20.0
Pusher propeller	0.0	0.8	0.0	0.8	0.0
Deicing kit components	62.0	75.0	70.0	67.0	70.0

Figure N-I-2. (U) Anti-icing/deicing weight estimates (all values in lb).

Protected Area	Technical Risk	Applicability	Recommended Methods
1. Main and tail rotors	Low	All	Electrothermal cyclic deicing.
2. Propellers	Low	Tilt Rotor, Compound, Compound ABC	Electrothermal deicing.
3. Engine and induction system	Low	All	Bleed air anti-icing.
4. Flight probes	Low	All	Electrothermal anti-icing.
5. Windshield	Low	All	Electrothermal anti-icing.
6. Empennage	Low	All	Pneumatic boots.
7. Wings	Low	Tilt Rotor, Compound, Compound ABC	Pneumatic boots.
8. Weapons/target acquisition	Low	All	Electrothermal anti-icing.
			UNCLASSIFIED

Figure N-I-3. (U) Recommended anti-icing/deicing methods.

and reduce the SFDR logic to that of a housekeeping task for the data to be retained in the memory unit.

b. (U) The pertinent issue is the degree of integration of the SFDR into the FD/LS functions provided in the MEP. It is desired that the integrated system continuously monitor the MEP to detect and locate faults and to display and retain pertinent data for subsequent maintenance support and/or crash investigations. The required characteristics for crash investigation are identified in the draft tri-service military specification for an SFDR. These include the ability to collect, process, and retain in a crash-survivable memory parameters necessary for a comprehensive assessment of the mechanical and performance status of the aircraft. Additionally, the SFDR is required to retain maintenance-related data in a noncrash-survivable memory/display.

c. (U) The LHX MEP will include extensive employment of individual fault detection/location capabilities. The logic employed by the MEP microprocessors will generate status information on the Military Standard (MIL-STD) 1553 data bus which, in turn, can be transferred to the SFDR. The commonality of the microprocessors of the MEP and the SFDR, which complies with MIL-STD 1750, and both using the same Department of Defense standard software language (Ada) will ensure maximum exchange of information and ease of integration. Because of this interactive approach used by the FD/LS and the SFDR, much of the task can be accomplished by the MEP. The specification identifies a power consumption of 45 watts maximum and a maximum weight of 9.5 lb.

d. (U) The technical risk is low because the SFDR will have already been developed, evaluated, and accepted by the military prior to its 1987 FSD application to the LHX. If a significant portion of the functions of the signal ac uisition unit can be integrated into the FD/LS of the MEP, cost and weight of the SFDR can be reduced to that necessary for the crash SMU; i.e., less than $5,000 and 3.5 lb.

e. (U) The recommended approach is to emp y the tri-service SFDR. The SFDR and the FD/LS will share microprocessors and software to the maximum extent practical. The rationale for the selected approach is the low-risk development effort and demonstrated reliability of the system.

N-I-7. (U) ONBOARD REFUELING SYSTEM.

a. (U) The onboard refueling system is required for the LHX configuration to provide refueling capability from fuel sources where pumping and filtering facilities are not available. The desired features of this system include light weight, low operation and maintenance costs, and not presenting a safety hazard. The onboard refueling system will consist of refueling/defueling valves, full quantity and low-level sensors, high/low-level shut-off valves, self-sealing breakaway vent valves, and pumps, ports, and methods which permit fueling by gravity, pressure, and suction (siphoning). The methods will include closed-circuit and single-point refueling techniques and the ability to refuel without the use of auxiliary pumps. The system will be compatible with North Atlantic Treaty Organization (NATO) standard refueling nozzles and procedures. When using pressure fueling, the minimum rate will be 300 gallons per minute (gpm) when all tanks are fueled simultaneously or 125 gpm when tanks are fueled separately.

b. (U) The power source for suction refueling will be provided by a hydraulic pump because an electrical pump is not desired (fire hazard) and a pneumatic source requires too much power.

c. (U) The candidate system consists of a hydraulically driven suction fuel pump requiring 1-3 HP and capable of delivering 125 gpm, which enables filling of any LHX configuration in less than 2 minutes.

d. (U) The cost and weight of the system are considered negligible because the system will essentially involve a modification of existing fuel plumbing and the employment of existing power sources. The technical risk is

considered low. The addition of a hydraulically driven pump and plumbing will increase the system's weight by approximately 3 lb and will cost approximately $3,000.

e. (U) The recommended approach is to employ the APU as the power source for the hydraulically driven motor/pump combination. The onboard refueling system will be configured as a built-in design.

N-I-8. (U) FIRE DETECTION, WARNING, AND EXTINGUISHING (FDWE) SYSTEM.

a. (U) The FDWE system consists of sensors, indicators, controls, and the extinguishing agent. The FDWE system must detect and extinguish a fire at the engine(s) or the APU installation without affecting the remaining power plants. The power plants are monitored by sensing units, two on each main engine and one in the APU compartment.

b. (U) The pertinent issue is the degree of FDWE system automation. There is no question as to the need of an extinguishing system; however, manual or automatic extinguishing is a consideration, as well as extinguishing bottle(s) used manually by the crew.

c. (U) The candidate FDWE system for all LHX configurations and variants consists of automatic sensing, logic processing, and extinguishing of propulsion system fires. The selection of automatic extinguishing is predicated by the high pilot workload and the quick reaction time requirement for extinguishing. The MEP contains the logic-processing capability. As a result, the logic processing in the MEP can be used to activate the proper fire extinguishing channel automatically.

d. (U) The technical risk for development of an LHX FDWE system is low. Similarly, the automatic extinguishing logic which will be developed along with the FD/LS software will be a low-risk item. The current weight of the UH-60A FDWE system is 30.6 lb, and the LHX FDWE system will weigh 9-10 lb. Cost impact is not known at this time.

e. (U) The recommended FDWE system has been developed for the private sector; therefore, there should be no problems associated with having a flightworthy system available prior to start of the LHX FSD.

N-I-9. (U) CARGO HANDLING AND RESCUE HOIST.

a. (U) Cargo handling requires cargo hook provisions for the LHX-Utility and SCAT. The SCAT cargo hook will be a single-hook configuration with a 2,000-lb capacity but without a snubbing capability. LHX-Utility variants to be addressed include the capability for stabilizing the external load, consideration of 2,000- and 3,500-lb external loads, and consideration of cargo doors required for litter evacuation. The pertinent issues include the following:

(1) (U) The need for the capability of precision hover for external cargo handling and personnel rescue using the rescue hoist. A need currently

exists for the capability of round-the-clock, all-weather cargo handling in order to perform aerial cargo movement and/or resupply operations.

(2) (U) The need for built-in multiple cargo hook attachments to provide an improved degree of external cargo load stability during high-maneuver flight activities.

b. (U) The hook system must include the pilot-actuated normal electrical release. The hook control panel, wiring, and connector in the cabin floor well will be permanently installed on each LHX-Utility aircraft. Another necessary characteristic is precision hover. Stability augmentation systems for attitude hold and Doppler radar for altitude hold are built into the automatic flight control system (AFCS). This is considered essential for conducting all-weather, round-the-clock external cargo operations (both load acquisition and drop-off) to respond to the current deficiencies cited in the Aviation and Logistics Combat Service Support and Mission Area Analysis documents. Several methods of load stabilization are possible which can enhance the safety of external transport missions and the aircraft's handling qualities.

c. (U) Options are available for the various types of external cargo hooks. The most commonly used hook is the nonswiveling type. The alternative is a swiveling hook with load transmission through ball or tapered roller bearings. For redundant electrical (with mechanical backup) opening methods, a swiveling hook requires slip rings to transmit the electrical signal. In the past, slip rings have created reliability problems and preventive maintenance actions; however, a swiveling hook will prevent sling and/or sling apex twistup on the hook. It is estimated that an LHX-Utility nonswiveling hook would weigh 4 lb for a 2,000-lb capacity hook and 11 lb for a 3,500-lb capacity hook. A swiveling capacity is estimated to add about 2 lb to these weights.

d. (U) There are at least three options available for external load stabilization. The first option (dual tandem nonswiveling hooks) for aircraft with a single main lift point is a requirement for a very reliable system to assure that both hooks open if the load is lost on one hook. The safety device for this configuration consists of a lanyard from the load to a trigger that trips both hooks.

e. (U) A second load stabilization method is the Active Arm External Load Stabilization System (AAELSS). Four pivoted sling load arms are attached to the bottom of the aircraft. As the load swings or sways, the load arm movement rate is electronically sensed. Hydraulic cylinders attached between the arms and the airframe are actuated to dampen the fore-aft and/or lateral movement of the load. The system is not recommended for a light utility aircraft due to its weight, complexity, and power requirements.

f. (U) A third candidate for load stabilization is the load snubbing concept. A hoist kit with the load cable is extended through the cabin floor, the hoist cable is extended down to the load from a hover, the acquisition is made, and the load is reeled up to the helicopter until it is snubbed into one

or more bellmouth-shaped fittings on the bottom of the aircraft. The system then permits normal nap-of-the-earth (NOE) flight without load oscillations. The system has the advantage of permitting load acquisition from a high hover position. The snubbing hoist power demand would probably require a hydraulic drive system to reduce the total electrical load. The snubbing concept is desired if high-maneuverability NOE flight with an external load is deemed necessary. From the data of figure N-I-4, it can be seen that complete external load stabilization is costly.

g. (U) For day/night, adverse-weather, and/or external cargo load acquisition in swirling dust or snow, a precision hover capability is required. This capability is inherent in both the LHX-SCAT and LHX-Utility MEPs. All axes of the AFCS are coupled to the Doppler radar and other sensors, and a hover-hold mode will be available to the pilot. An additional option exists for enhancing all-weather load acquisition with a "hands-off" hook engagement. Concept optimization of the Low Visibility Load Acquisition System is underway at the US Army Applied Technology Laboratories (US Army Aviation Research and Development Command). This system is applicable to either utility or medium/heavy lift external load operations. Either fiber-optic sensors or a television camera pickup on the bottom of the aircraft will depict the position of the cargo hook to the sling apex. This picture can be displayed on the instrument panel or on special pilot glasses which readily fit behind the night vision goggles. When hovering in the vicinity of the apex, the pilot can "fly the hook" onto the apex. After the apex is in the hook, a "green light" advisory will tell the pilot he can execute the liftoff safely.

h. (U) The rescue hoist should meet the performance criteria of the typeclassified utility helicopter high-performance hoist (HPH). It is 28-volt direct current (vdc) powered, and the control panel is part of the kit. The hoist has a capacity of up to 250 feet per minute (fpm) with a 300-lb load and up to 125 fpm with a 600-lb load. The rescue hoist installation could be a vertical pipe (part of the kit) mounted near the middle of the center-of-gravity range with a swing-out-the-door capability. An alternative would be external mount points over the troop door. Either method adds to the justification for a miniumum 4-foot x 7-foot door.

i. (U) The required operational capability requirement for an HPH was to achieve up to 500-fpm extension/retrieval cable speeds with automatic deceleration features, an emergency cable cutter, and a backup hand crank retrieval mode. The achievement of the 0- to 500-fpm cable speed was nearly impossible at the stated loads without designing a completely new hoist. Consequently, a modified Western Gear Hoist, having a capacity of 250 fpm with a 300-lb load and 125 fpm with a 600-lb load was type-classified in 1980. The hoist assembly weighs 174 lb with a swiveling door post-type installation included. The hoist is 28-vdc powered and draws about 125 amperes. The hoist, with controller and pendant, weighs about 134 lb. The swiveling post support weighs about 40 lb. The hydraulic hoist, on the other hand, has a capacity of 0-250 fpm with a 600-lb load. Total system weight, including hoist with heat exchanger and fairing, control station, pendant, and boom, is 90 lb.

Configuration and Trade-Offs	Estimated Cost ($FY 84)	Estimated Weight (lb)	Technical Risk	Research and Development Required	TOA Recommendations
Cargo handling (external)					
1. Hook structural provisions (including controls)					
a. 2,000-lb capacity	2,000	3	None	None	
b. 3,500-lb capacity	2,000	4	None	None	
2. Single nonswiveling hook					
a. 2,000-lb capacity	+1,500	+4	None	None	
b. 3,500-lb capacity	+2,000	+11	None	None	
3. Single swiveling hook					
a. 2,000-lb capacity	+2,500	+6	None	None	
b. 3,500-lb capacity	+3,000	+13	None	None	UNCLASSIFIED

Figure N-I-4. (U) LHX-Utility cargo handling (concluded on next page).

Configuration and Trade-Offs	Estimated Cost ($FY 84)	Estimated Weight (lb)	Technical Risk	Research and Development Required	TOA Recommendations
4. Load stabilization					
a. Dual tandem nonswivel hooks					
(1) 2,000-lb capacity	7,500	16	Low	None	
(2) 3,500-lb capacity	8,500	32	Low	None	
b. AAELSS	+80,000	+350	Medium	FSED ($500K)	Not recommended for LHX; too complex for utility helicopter.
c. Load snubbing system					
(1) 2,000-lb capacity	+50,000	+300	Medium	FSED ($500K)	Recommend for high maneuverability and NOE external load flight.
(2) 3,500-lb capacity	+60,000	+350	Medium		
5. Precision hover capability	+0	+0	Low	None	Incorporated in MEP.
6. Low visibility load acquisition	+50,000	+25	Low	Flight test ($400K)	Recommend for all-weather external cargo operations.
Cargo handling (internal)	+180	+3	None	None	Recommend without reservation.
UNCLASSIFIED					

Figure N-I-4. (U) (concluded)

j. (U) The issue of rescue hoist power sources produces another trade-off. If an electrically powered hoist is used, provisions are simple with only a suitable electrical quick-disconnect required. If a hydraulically powered hoist is chosen, heavy quick-disconnects are required. A pneumatically driven hoist would require a pressure-in quick-disconnect and a high-speed (to achieve the required torque) pneumatic motor. The bleed air required would be significant and, since the hoist is used basically in an out-of-ground-effect hover, the power drain on the main engine(s) would probably be excessive. Therefore, a pneumatically driven hoist is not recommended. Two options exist for an electrically driven hoist. The current new HPH is 28-vdc powered and uses about 125 amperes. A 115-volt alternating current (vac), 400-Hertz (Hz) version would require a research and development effort. The 28-vdc version (see figure N-I-5) is recommended.

k. (U) The following four items summarize the recommended approaches for cargo handling and rescue:

(1) (U) For external load missions, the dual-hook load system for stabilization is recommended; a third hook for lighter, single-point lift loads is recommended also.

(2) (U) For round-the-clock, adverse weather external load missions, the low-visibility load acquisition system is recommended. The capability for precision hover is already incorporated into the MEP for other reasons.

(3) (U) For internal cargo loads, the inclusion of a tiedown ring pattern in the cabin floor is recommended.

(4) (U) The recommended rescue hoist is the current 28-vdc powered hoist with cable speeds of 0-250 fpm. The recommended method of mounting will have the capability for swinging the payload into the cabin.

N-I-10. (U) FINDINGS (SUBSYSTEMS).

a. (U) The APU (versus the battery) provides the greatest operational advantage in terms of reduced fuel usage, dispatch reliability, flight safety, and field maintenance.

b. (U) The electrical subsystem design is completely dependent upon MEP, weapon system, and icing requirements. Also, this subsystem has to be designed to handle the maximum continuous power as well as the peak power loads even though some functions (icing requirements) may be provided in kit form.

c. (U) Pneumatic subsystem sizing is significantly dependent upon the crew CB protection level required. If cockpit overpressure protection is necessary following combat damage, then considerable weight and power penalties are incurred.

Configuration and Trade-Offs	Estimated Cost ($FY 84)	Estimated Weight (lb)	Technical Risk	Research and Development Required	TOA Recommendations
Rescue hoist (provisions only)					
1. Hoist installation provisions					
a. Swiveling post provision and power outlet					
(1) Electrical drive	1,300	6	None	None	Recommend as full payload swing-in is desired.
(2) Hydraulic drive	1,800	10	None	None	
b. Over-the-door provision and power outlet					
(1) Electrical drive	1,300	6	None	None	
(2) Hydraulic drive	1,800	10	None	None	
2. Rescue hoist kit					
a. Swivel post mount	15,000	40	None	None	
b. Electrical drive					
(1) 28 vdc	45,000	135	None	None	Current 28-vdc HPH recommended (0-300 fpm).
(2) 115 vac, 400 Hz	45,000	130	Low	$2.5M	
c. Hydraulic drive	65,000	102	None	None	UNCLASSIFIED

Figure N-I-5. (U) LHX-Utility rescue hoist.

d. (U) Fly-by-light/wire flight controls will reduce the number of hydraulic actuators resulting in improved reliability, availability, and maintainability characteristics and weight savings. However, weight reductions associated with the use of composities for hydraulic components are high-risk and may not be cost-effective as the hydraulic subsystem is currently less than one percent of the aircraft empty weight.

e. (U) The hybrid ECS (cockpit overpressure plus individual suits) provides maximum aircrew CB protection during combat; when aircrews do not wear protective clothing (peacetime) sufficient cooled/heated air is available.

f. (U) The OBOGS output will be sufficient to permit the LHX crew to fly at 18,000 feet; also, sufficient nitrogen will be available from the NIU section of the OBOGS to prevent fuel cell fires or explosions.

g. (U) For icing requirements, a weight savings of 62 to 75 lb will be realized by provisioning via kits.

h. (U) The required characteristics for crash investigations are identified in a draft tri-service specification for an SFDR. These include the ability to collect, process, and retain in a crash-survivable memory parameters necessary for a comprehensive assessment of the mechanical and performance status of the aircraft as well as maintenance-related data in a nonsurvivable (crash) memory. The commonality of the microprocessors of the MEP and the SFDR, both using the same software (Ada), will ensure maximum exchange of information and ease of integration (MEP, SFDR, and FD/LS).

i. (U) The onboard refueling system will be configured as a built-in design due to its low weight (3 lb) and operational benefits (saves time/work). The system will be compatible with NATO standard refueling nozzles and procedures.

j. (U) The candidate FDWE system for all LHX configurations consists of automatic sensing, logic processing, and extinguishing of propulsion system fires. The MEP contains the logic-processing capability. The UH-60A FDWE system weighs 30.6 lb; the LHX FDWE system will weigh 9-10 lb.

k. (U) Load stabilization is desired to prevent external cargo oscillations while promoting high-maneuver NOE flight. Load stabilization is not required for the SCAT cargo hook. The capability for precision hover (desired for cargo/rescue) is already incorporated into the MEP for other reasons. The preferred method of mounting the rescue hoist is to have the capability for swinging the payload into the cabin.

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ANNEX II TO APPENDIX N

STRUCTURES - PERTINENT ISSUES AND SYSTEM CHARACTERISTICS (U)

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ANNEX II TO APPENDIX N

STRUCTURES - PERTINENT ISSUES AND SYSTEM CHARACTERISTICS (U)

N-II-1. (U) PRELIMINARY STRUCTURES ISSUES.

a. (U) Airframe. The primary issue with respect to airframe structure technology is the ability to field an airframe which is lightweight, low-cost, and at the same time, compatible with the overall required/desired systems attributes for the Family of Light Helicopters (LHX).

b. (U) Hub and Hinge. The primary issue with respect to hub and hinge structure technology is the ability to field an assembly which has favorable damage tolerance/fail safety, fatigue life, and reliability, availability, and maintainability (RAM) characteristics and is compatible with the dynamic and performance requirements.

c. (U) Rotor Blade. The primary issue with respect to the rotor blade is the ability to design, develop, and field a low-cost blade which has favorable damage tolerance/fail safety, fatigue life, and RAM characteristics and is compatible with the dynamic and performance requirements.

d. (U) Landing Gear. The primary issue with respect to landing gear structure technology is the ability to design, develop, and field a lightweight, low-cost landing gear system which is compatible with the crashworthiness and forward flight performance requirements.

N-II-2. (U) RELATED STRUCTURE ISSUES.

a. (U) Decontamination. Because the use of nuclear, biological, and chemical (NBC) weapons has become a tactical reality, the LHX must be capable of safe, efficient operation and support in a contaminated environment. Not only must the crew be protected from NBC hazards, the aircraft/airframe should be able to withstand repeated contamination/decontamination cycles without degrading the structural characteristics (strength, stiffness, life) of the system. Therefore, the entire aircraft must be designed to both minimize exposure to NBC contaminants and to facilitate decontamination after an exposure has occurred.

b. (U) Structural/Retirement Life. A potential alternative to the LHX is the use of a derivative aircraft. Therefore, the retirement life for potential candidate derivative aircraft airframes must be considered along with the projected retirement life of new system designs.

c. (U) Battle Damage Repair. As the helicopter system becomes less vulnerable to ballistic threat, there is a corresponding increase in the number of aircraft returning with damaged structures which require repair. The issue of battle damage repair, therefore, has been considered as a part of the reliability and maintainability characteristics for the LHX.

N-II-3. (U) AIRFRAME STRUCTURES.

a. (U) Composite Airframe Technology (Baseline). The application of composite materials and construction techniques is equally applicable to the five configurations (helicopter, compound helicopter, advancing blade concept (ABC), compound ABC, and tilt rotor) considered. The baseline technical approach is the maximum practical application of advanced composite materials to the LHX airframe. The Advanced Composite Airframe Program (ACAP) is the primary technological base for this technical approach.

b. (U) Metallic Airframe Technology. The application of conventional metallic airframe construction techniques to the primary airframe structures and the application of composite materials and construction techniques to the secondary structures are considered equally applicable to all configurations. The UH-60 Black Hawk and the AH-64 Apache are the technological base for this technical approach.

c. (U) Derivative Aircraft. The use of existing airframe structures with minimal changes to the structural configuration will be considered. Changes to the structural configuration to accommodate weapon systems, local reinforcement of basic aircraft structures, and replacement of secondary structures with lighter weight, lower cost structural designs are allowed.

N-II-4. (U) AIRFRAME MATERIAL CHARACTERISTICS.

a. (U) Composite Construction. The application of composite materials to the fabrication of airframe structures is considered to be the baseline for this LHX Trade-Off Analysis (TOA). Composite airframes are being demonstrated under the Army's ACAP in which both Bell and Sikorsky have designed and developed an ACAP helicopter and are currently in the process of fabricating three airframes each, one of which will be fully assembled and flight-tested. Boeing Vertol, under company funding, is developing a composite airframe for the Model 360, a CH-47 derivative aircraft. From an overall viewpoint, there are three composite airframe construction techniques which will be discussed in the following subparagraphs.

(1) (U) Large half-shell skin-stringer construction. The large half-shell skin-stringer design is based on the premise that composite skin, frames, and longerons can be laminated and co-cured in a unitized structural arrangement that has a minimum number of joints and load path interruptions. The design is divided into the largest sections commensurate with practical manufacturing and tooling techniques in order to minimize the number of parts. The main fuselage shell is fabricated in order to minimize the number of parts. The main fuselage shell is fabricated in left and right halves that are joined along the lower centerline of the airframe. The fuselage roof is divided into forward and aft sections. The forward roof section is designed for mounting of the main transmission, controls, and other dynamic system components. The aft roof requires the use of polyimide resin systems and special curing processes to accommodate high-temperature and fireproofing requirements in the engine compartment. The nose section, closure bulkheads, floor panels,

cockpit window frames, and tailboom section are joined with the main fuselage shells and roof sections in the final assembly of the airframe structure. Figure N-II-1 shows the composite material weight by percentage of airframe weight. Figure N-II-2 shows likely material applications for various airframe components.

(2) (U) Large half-shell honeycomb sandwich structure. The large half-shell sandwich structure is typical of the airframe design proposed by Boeing Vertol for the ACAP. The half-shell sandwich design basically adheres to the monocoque principle by reacting externally applied loads directly into the shell itself, thereby minimizing the need for numerous frames, beams, and bulkheads. However, due to necessary cutouts, such as doors and access panels in the shell, a minimal number of supportive substructure details are necessary. The resulting airframe design is simple and clean with the shell virtually devoid of all major joints, except for the clamshell assembly splices. By employment of large bonded assemblies, the sandwich half-shell approach offers a 90-percent reduction in fasteners and a 75-percent reduction in parts, compared to the metallic baseline. In contrast, however, this approach offers lower potential for weight savings and high tooling cost for an airframe in the 8,000- to 10,000-pound (lb) gross weight category. The tooling method for this design requires integrally heated left- and right-hand clamshell molds, both in excess of 30 feet long. This tooling approach also necessitates constant skin thicknesses, which not only restricts the weight savings but also significantly reduces design flexibility. The large fuselage clamshell sections extend from forward of the nosewheel bulkhead to the aft end of the vertical stabilizer support structure. Integrally molded components include the crashworthy understructure; the cockpit and cabin structure, stiffened by vertical shear webs; the rear cabin semibulkhead; and the tailboom with vertical stabilizer torque box. The windshield post, the floors, the engine deck, and the horizontal stabilizer comprise major structural components that are secondarily bonded to the fuselage half-shells. The fuselage half-shells, frames, and bulkheads are fabricated using Kevlar face sheets and Nomex honeycomb cores. Roof support and underfloor beams are similarly fabricated with graphite face sheets and Nomex cores. Cockpit and cabin floor panels utilize glass/epoxy skins and Nomex cores.

(3) (U) Skin-stringer with large modular subassemblies. The Sikorsky ACAP is typical of this approach to fabricating the airframe structure. The skin-stringer modular approach is designed for substantial reduction in parts count and fastener count through the use of co-cured and adhesively bonded subassemblies. Each modular component or subassembly represents a complete, independent producible entity. In this concept, the final assembly of the complete airframe is accomplished with the mechanical fastening of the subassemblies into one complete airframe unit. The large subassembly approach offers inherent design flexibility with regard to airframe assembly techniques. The Sikorsky ACAP mechanical fasteners are reduced by 80 percent over a conventional metallic skin-stringer construction; however, the number of fasteners could be further reduced through the use of adhesive bonding in the final assembly stages. Maintainability can be further enhanced by the incorporation of local reinforcing repair strips that permit modular replacement of structurally damaged portions of the airframe.

Material	Percent Weight
Graphite	53.0
Kevlar	18.9
Metal	8.2
Other	20.9
	100.0

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Figure N-II-1. (U) Airframe material weight.

Material	Used In
Graphite/epoxy	Longerons, stringers, frames, bulkheads, tailboom, fin, horizontal stabilizer, forward roof, cowlings
Kevlar/epoxy	Fuselage skin, windshield frame, doors
E-Glass/epoxy	Cargo floor
Graphite/polyimide	Aft roof, firewalls
S-Glass/polyimide	Firewalls
Nomex core	Bulkheads, forward roof, floors
HRP core	Firewalls, aft roof
Rohacell foam	Stiffeners, cowlings
Metal	Fittings, fasteners
Miscellaneous	Adhesive lightning protection

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Figure N-II-2. (U) Airframe materials usage.

(a) (U) The major subassemblies include the lower forward fuselage, the cabin roof, the cabin sides, the rear fuselage, and the empennage structures. The lower forward fuselage provides an energy-absorbing substructure, crew and cargo floors, and attachment points for the nose landing gear. The cabin side panels are coupled with the cabin roof structure, which includes the transmission support beams, to provide a cabin with adequate structural integrity to maintain at least 85 percent of the cabin volume in a crash. In addition, necessary strength is provided to prevent the high-mass items from penetrating the troop and cargo areas. The rear fuselage structure includes the engine deck support structure, the fuel system, and the avionics and equipment bays. The empennage consists of the tailcone, which can be designed for 23-millimeter (mm) survivability, and the horizontal and vertical stabilizers.

(b) (U) A typical material distribution for an airframe constructed using large subassemblies of skin-stringer composite construction is shown in figure N-II-3. Kevlar is used primarily for skin structure while graphite is used in beams, bulkheads, and frames, as well as for local reinforcement of structures. The tailboom, which is stiffness-critical, is constructed of graphite.

Material	Percent Usage
Kevlar	30.9
Graphite	26.7
Aluminum	8.0
Steel	7.6
Glass/Plas	5.6
Fiberglass	4.6
Other	16.6
	100.0

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Figure N-II-3. (U) Typical material distribution by weight.

b. (U) Metallic Construction. The application of metallic construction, primarily aluminum skin-stringer, has long been the state of the art in airframe construction. All existing Army aircraft use metallic airframe construction techniques in the primary structure. Only in the past 10 years have composites emerged into the airframe structure and then only in lightly loaded or nonstructural components. The exceptions to this are the Sikorsky helicopters which have used composite construction in the cockpit/canopy frames.

c. (U) Sheet Metal Semimonocoque Construction. The airframe uses conventional sheet metal semimonocoque construction techniques, except in bulkheads and some skin panels which are of bonded aluminum honeycomb sandwich construction. Machined aluminum forgings are used in areas with high concentrated loads.

N-II-5. AIRFRAME PRIMARY CHARACTERISTICS.

a. (U) Weight. This section quantifies the projected airframe (body, tail, and nacelle) and wing structure weights for the technical approaches/candidate systems for the LHX. For a new aircraft system there are two primary approaches to the construction of the airframe. The first approach is conventional metallic skin-stringer construction. The weights for conventional metallic airframe structures were developed using the preliminary design element's parametric weight-estimating equations. The second approach, which is the baseline for the LHX TOA, is the maximum practical application of composite materials to the airframe and wing structures. The weights for an all-composite airframe were developed by applying a composite material technology factor to the parametric weight equations. These technology factors were originally derived from the Joint Vertical Lift (JVX) and LHX technology assessments and the ACAP and were revised/updated during the LHX Trade-off Determination. The advanced composite material weight reductions are shown in figure N-II-4. A summary of the baseline aircraft, airframe, and wing structure weights for various LHX configurations is shown in figure N-II-5. A summary of the matallic aircraft, airframe, and wing structure weights for various LHX configurations is shown in figure N-II-6.

Component	Helicopter	Compounds	ABC	Tilt Rotor
Wing group				
Basic structure	--	20	--	20
Control surface	--	21	--	21
Tail group				
Horizontal	30	30	30	30
Vertical	25	25	30	35
Body group	28	28	28	28
Nacelle group	5	5	5	5
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Figure N-II-4. (U) Advanced composite material weight reduction (percent).

Aircraft Configuration	Composite				
	Body	Tail	Nacelle	Wing	Total
SCAT helicopter	852.8	81.4	109.1	--	1,043.3
Utility helicopter	938.4	105.5	64.6	--	1,108.5
SCAT compound	877.9	101.5	70.2	169.9	1,219.5
Utility compound	1,010.1	101.5	70.2	169.9	1,351.7
SCAT ABC	746.9	46.4	64.9	--	858.2
Utility ABC	827.7	46.4	64.9	--	939.0
SCAT compound ABC	836.8	61.1	80.1	--	978.0
Utility compound ABC	985.5	61.1	80.1	--	1,126.7
SCAT tilt rotor	777.4	163.3	194.2	533.1	1,668.0
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Figure N-II-5. (U) Baseline airframe and wing structure weights (lb).

Aircraft Configuration	Metallic				
	Body	Tail	Nacelle	Wing	Total
SCAT helicopter	1,184.4	118.0	118.6	--	1,421.0
Utility helicopter	1,303.4	148.0	70.0	--	1,521.4
SCAT compound	1,219.3	142.5	76.3	202.3	1,640.4
Utility compound	1,402.9	142.5	76.3	202.3	1,824.0
SCAT ABC	1,037.4	71.3	70.5	--	1,179.2
Utility ABC	1,149.6	71.3	70.5	--	1,291.4
SCAT compound ABC	1,162.2	93.4	87.1	--	1,342.7
Utility compound ABC	1,368.8	93.4	87.1	--	1,549.3
SCAT tilt rotor	1,079.7	211.9	211.9	635.7	2,139.2
UNCLASSIFIED					

Figure N-II-6. (U) Metallic airframe and wing structure weights (lb).

(1) (U) The sensitivity of the airframe weight (body, tail, and nacelle) to the degree of composite structure application was developed because it is conceivable that composites could be applied only to portions of the airframe structure. Using the utility helicopter airframe to develop a sensitivity of the airframe weight to the percent of composite materials utilized, the airframe weight was apportioned into the following weight categories: cabin-cockpit, transition section, tailcone, doors and fairings, horizontal stabilizer, vertical stabilizer, and nacelles. The resulting weights for the composite baseline and a conventional metallic airframe are shown in figure N-II-7.

(2) (U) The incorporation of other technologies into the LHX airframe has a direct impact on the weight of the airframe structure as well. These additional technologies include the incorporation of the modular repair strip design concept, crashworthiness to the UH-60/AH-64 level, 23mm ballistic tolerance in the tailboom structure (12.7mm included in baseline), NBC protection, and reduced radar cross section. The weight technology factor for each of these areas is shown in figure N-II-8. The technological factor is a multiplier applied to existing system weights to calculate new system weight estimates.

	Composite	Metallic	Percent Reduction
Cabin	230.9	391.0	41
Cockpit	104.9	143.4	27
Transition	297.7	417.1	29
Tailcone	117.3	130.3	10
Doors/Fairings	187.6	221.6	15
Horizontal stabilizer	22.1	36.8	40
Vertical stabilizer	83.4	111.2	25
Nacelles	64.6	70.0	8
Overall	1,108.5	1,521.4	27

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Figure N-II-7. (U) LHX utility helicopter airframe weights (lb).

Military Characteristic	Technological Factor	Applicable Weight Group
Modular repair (composite design only)	1.01	Body group
23mm ballistic tolerance (tailboom)	1.01	Body group
Crashworthiness (UH-60/AH-64)	1.04	Body group
Radar cross section (ACAP levels)	1.045	Body group Tail structure Nacelle
NBC	1.03	Body group

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Figure N-II-8. (U) Weight technological factors for other military characteristics.

b. (U) Damage Tolerance/Durability. The airframe structure, particularly the skin surface, is subject to damage during ground handling, takeoffs and landings, as well as in flight. The two primary damage scenarios are high-energy impact conditions, such as ballistics, and the low-energy impacts where objects such as tools and wrenches are dropped on the surface. In this section, the primary concern is the low-energy impact condition. Composite structures are inherently more resilient under low-enery impact conditions than are metallic structures due to the high strain-to-failure characteristics of composites. Composites will deflect when impacted and will return to their original molded contour as long as the impact energy has not exceeded design limits. Metallic skins, on the other hand, will tend to dent and take a permanent set under similar impact conditions. Therefore, in the metallic structure, repair may be required.

(1) (U) From a durability viewpoint, metals have exhibited good long-term durability. Metals do, however, experience corrosion problems which require attention and result in a high repair rate to correct corrosion-associated failures. Corrosion problems are essentially eliminated in the composite airframe.

(2) (U) Moisture absorption problems experienced with resin and adhesive systems have been eliminated in the resin systems currently used.

(3) (U) Airframe joints which have always been a concern in metallic structures from a fatigue viewpoint are much less a concern in composite structures. Composites have greater fatigue strength and lower notch sensitivity than do metals. With appropriate consideration given to fail-safe or safe life design in composites, the notch sensitivity and crack propagation rate can be reduced.

c. (U) Reliability. In metallic airframe structures, failures are predominantly a result of fasteners, cracks in skins and other components, and chafing and wear. These metallic airframe failure modes historically account for approximately 89 percent of all failures.

(1) (U) The single most significant contributor to failures in metallic airframes is fasteners, which are generally rivets that are loose, have heads popped off, or have tails insufficiently driven. This failure mode is significantly reduced by virtue of the substantial reduction in rivets/fasteners in composite airframe design configurations.

(2) (U) Cracking. Cracks in skin and frame structures are the second most predominant failure mode in metallic structures. After a crack initiates in a metallic skin, it tends to propagate under cyclic stress even when the stress levels are below design limits. However, in composite structures, cracks are inhibited from propagation. Furthermore, cracks in composites generally remain within a given laminate and do not extend through the thickness of the structure.

d. (U) Repairability. All metallic structures can be repaired; however, most bulkheads, major frames, and fittings require jigging and special forming. Repairability of composite airframe structures varies with the type of material, size, and location. Composite airframe designs, however, will provide for a maximum level of repair with a minimum number of special tools and a minimum degree of special training.

(1) (U) Using a modular design approach, the aircraft is designed in sections or modules sized to be handled in the field. When large area damage occurs, the airframe module or modules that are damaged are cut out along prespecified trim lines. The trim lines are located along built-up areas in the structure called repair strips. A replacement module is produced from spares or cannibalized from unrepairable aircraft, and the replacement module is then installed.

(2) (U) Simple nonstructural repairs on metallic aircraft usually can be accomplished in 1.0-3.0 hours. Because of preparation time, structural repairs on metallic aircraft often exceed 3.0 hours. Major structural repairs are estimated to require 2-4 hours, depending on the type of repair and location on the airframe. Maintainability predictions developed in the ACAP reflect mean-time-to-repair (MTTR) hours for composites approximately equal to those of the metallic structure.

(3) (U) Access to internal structural surfaces and internally located components is necessary for direct visual inspection of the composite structure, as well as for removal and replacement of subsystem components. Incorporation of the access panels and removable fairings can be incorporated in the design of either a metallic or a composite airframe structure with minimal difficulty.

e. (U) Battle Damage Repair. Battle damage aircraft will require assessment and repair to return the aircraft to combat-ready status. In the design process, assessment techniques and quick-fix repair kits must be considered and incorporated as appropriate. Technical manuals and training literature will be developed that will assist field maintenance personnel in conducting damage assessments of critical composite airframe structures. Repair kits will be available for those areas that allow for quick fix.

f. (U) Reliability-Centered Maintenance (RCM). The RCM techniques must be applied during the design process whether the airframe is constructed using metals or composites. This process must consider trade-offs on a component-by-component basis considering safety and ability to monitor and inspect. Composites will provide an advantage for RCM in that the inherent damage tolerance and slow damage propagation of the composite structure may enable components which are typically designed to have a specified time between overhaul to now be specified for "on-condition" replacement.

g. (U) Ballistic Tolerance. Composite airframe structures in general exhibit better residual strength characteristics after ballistic damage than do metallic airframe structures because the composite structures are much less notch-sensitive. The primary areas of concern are the highly loaded areas such as the transmission and engine mount area, major structural beams and longerons, the tailcone structure, and stabilizers.

h. (U) NBC Considerations. Because use of NBC weapons has become a tactical reality, Army aircraft must be capable of safe, efficient operation and support in an infected environment. Not only must the crew be protected from NBC hazards, the aircraft/airframe should be well adapted to repeated contamination/decontamination cycles with no degradation of structural material properties. As a result, several additional structural and material considerations must be made to ensure a durable and reliable airframe design.

(1) (U) The materials used in aircraft construction must be compatible with solutions of decontamination. Self-limiting active solution hydrochloride (SLASH), developed by the US Navy, is tentatively considered the optimum chemical decontaminant for aircraft because it is cheap, easy to apply, and self-neutralizes in 2 to 3 minutes. Although SLASH has been proven effective for the traditional aluminum aircraft, there is no decontamination currently available suggesting that this solution is compatible with advanced composite materials.

(2) (U) In summary, composite airframe structures are anticipated to provide improvements with respect to the ability to seal the aircraft. For example, prehung door concepts where the door and door jambs are fabricated integrally provide a superior capability for door sealing. The composite construction techniques utilize minimal mechanical fasteners and, as such, provide a cleaner surface and fewer areas for entrapped contaminants. However, the effect of contaminants on the composite structure and the associated ability to decontaminate the structure have not been established.

i. (U) Lightning Protection. Lightning protection for an aircraft with a metallic airframe can be handled quite simply because the airframe is conductive. The only special provisions required are the addition of jumper cables/ straps between the airframe, the rotor, and the landing gear system. However, for a composite airframe, protection against lightning strikes requires special provisioning because the typical composite airframe is nonconductive. There are a number of methods for applying a conductive coating to the airframe to provide a lightning current path; however, most add excessive weight penalities. A new method of protection being evaluated currently is a copper urethane paint which shows some promise.

j. (U) Crashworthiness. Both metals and composite materials may be used to achieve crashworthiness goals, but different design approaches must be considered to utilize the inherent properties of each material. Ductile metals, such as 2024 aluminum, can tolerate rather large strains, deform plastically, and absorb considerable energy without fracture or separation. Composites, on the other hand, generally exhibit a low strain-to-failure characteristic

behavior compared to metals. Because of this composite material characteristic, energy absorption must be achieved through innovative design configurations rather than through an inherent stress strain behavior as in metals.

k. (U) Detectability. Composite airframe construction techniques provide the flexibility to shape the airframes for reduced radar cross section with minimum impact on the airframe weight and producibility. In addition, composite material construction techniques lend themselves to incorporation of radar-absorbing material into the design with no structural or performance degradation.

l. (U) Weapon System Interface. The primary interface considerations between installed weapons and the airframe fall into vibratory fatigue loading due to weapon firing, temperature and pressure impingement on the airframe, and the necessity to jettison a weapon pod in the event of a hangfire.

(1) (U) Vibratory loading due to weapon firing must be considered in the detail design of the airframe. In a general sense, the composite structure will provide an advantage over the metal structure because the composite structure is less notch-sensitive and more fatigue-resistant.

(2) (U) Airframes have historically been designed by static conditions. The Army's position has been that the airframe has, for all intents and purposes, an infinite fatigue life. Fatigue analysis and fatigue testing of the airframe historically has not been conducted on the aircraft being considered for derivative LHX aircraft. As such, if the aircraft are flown within the existing V-n diagram (speed versus load), fatigue life of the airframe is inconsequential.

N-II-6. (U) RELATED IMPLICATIONS ON AIRFRAMES.

a. (U) Description. These candidate systems include: large half-shell skin-stringer composite construction, large half-shell honeycomb sandwich composite construction, large modular subassembly composite construction, conventional skin-stringer metallic construction, and derivative aircraft configurations.

b. (U) Schedule Consideration. Metallic skin-stringer airframe construction has been the state of the art in the aircraft industry for decades. Composite airframe construction, on the other hand, is an emerging technology. Composite construction is being used in production on a number of secondary structures. Both Air Force and civilian fixed wing aircraft have wing, empennage, and fairing structures in production. The application of composites to helicopters has until recently been limited to fairings, floors, and other secondary structures, although Sikorsky has been fabricating composite cockpit structures for two decades. The Army's ACAP is a 6.3A development effort to demonstrate the weight, cost, and other military characteristics of an all-composite airframe. Bell Helicopter and Sikorsky Aircraft have fabricated the first (tool proofing) of three airframes which will be fabricated as a part of the ACAP. The static and flight test article

will be completed in early 1984 with flight testing scheduled to be completed in 1984. In 1985 and 1986, militarization testing of the ACAP helicopters will be conducted. In summary, metal airframe construction is fully developed and composite construction will be fully demonstrated in time to support a 1987 LHX full-scale engineering development.

c. (U) Cost. In summary, composite airframe construction provides reduced recurring and nonrecurring production costs, as well as reduced operating and support costs as compared to metallic airframe construction techniques.

d. (U) Risk. In overall terms, the risk associated with the technical approaches for developing the LHX airframe fall into two categories. For a metallic airframe design, whether it is a new airframe or a derivative, the risk is considered to be minimal. The risk of designing a composite airframe, whether it is a new deisgn or a derivative of one of the two ACAP aircraft, is considered to be low to moderate. The risk of achieving various technical and management characteristics associated with composite airframe development for the LHX is identified in figure N-II-9.

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Risk Area	Risk
Program cost	Low
Program schedule	Moderate
Producibility	
Current technology	Low
Fully automated	Moderate
Weight savings	Minimal
Cost savings	Moderate
RAM improvements	Low
Ballistic tolerance	Low
Crashworthiness	Low
Detectability	Moderate
Dependence on critical materials	Low

Figure N-II-9. (U) Composite airframe risk assessment.

e. (U) RAM. Improved reliability is on the order of 68 percent for 1970s' metallic airframe technology over 1960s' metallic technology and a 40-percent improvement for composite technology over the 1970s' metallic technology. The MTTR of a composite airframe, as compared to a metallic airframe, is predicted to be 10 percent greater. However, the increase in reliability will more than offset the increased repair time, resulting in an overall improved aircraft availability.

f. (U) Training. Training requirements for an airframe fabricated using conventional skin-stringer metallic construction techniques are no different than the training requirements for existing airframes in the field today. For composite airframes, new training will be required for maintenance personnel who will be required to inspect and repair. The training requirements are not considered to be extensive or complicated, however, and could be readily mastered by basic or intermediate skill-level personnel.

g. (U) Integrated Logistics Support. The fielding of a composite airframe will result in a number of improvements in the supportability of the LHX airframe. Although the maintenance man-hours per event will increase slightly, the overall maintenance man-hours (MMH) per flight hour ratio will be reduced due to the substantial reduction in time between maintenance actions.

h. (U) Rationalization, Standardization, and Interoperability (RSI). There are generally no components of the airframe which would be standardized in the sense of being interchangeable/interoperable with any other type aircraft. There is the possibility that some airframe components could be designed to be interoperable/interchangeable between the LHX-SCAT and utility aircraft configurations. These components are the tailboom, the horizontal stabilizer, and perhaps the vertical tail.

N-II-7. (U) DESCRIPTION OF RECOMMENDED AIRFRAMES.

a. (U) Ranking of Alternative Approaches. A comparison of the two major technical approaches to airframe structures is provided in figure N-II-10. The final ranking of the alternatives based on the relative ranking of the specific characteristics is shown in figure N-II-11.

b. (U) Rationale for Ranking of Alternatives. Composite airframe technology provides a significant advantage over metallic technology from a weight viewpoint. Weight savings on the order of 27 percent in the airframe are projected. Airframe costs for 1970 and new metallic airframe technology are advantageous as compared to 1960s' technology because of improved system reliability which results in lower operating and support costs. Composite airframes, however, provide a significant reduction in production costs as well as an improvement in operating and support costs. Although metallic airframe structures are certainly producible, composite airframe structures offer the advantage of reduced manpower requirements and significant improvements in the ability to tailor the structural design to produce the desired military characteristics.

	New Metallic Airframe	New Composite Airframe
Weight		X
Cost		X
Damage tolerance/durability		X
RAM		X
Ballistics		X
NBC	X	
Crashworthiness		
Detectability		X
Lightning	X	
Risk	X	
Test, measurement, and diagnostic equipment (TMDE)	X	
Training	X	
Integrated logistics support (ILS)		X
RSI		

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X = Superior attribute/capability.

Figure N-II-10. (U) Airframe ratings.

1. New composite airframe.
2. ACAP derivative.
3. New metal airframe.
4. 1970s' technology derivative.

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Figure N-II-11. (U) Recommended ranking of alternatives.

N-II-8. (U) ROTOR HUB AND HINGE.

a. (U) The rotor hub and hinge assembly includes the components from the rotor shaft outboard to the blade attachment point. Two primary approaches for the rotor hub and hinge assembly will be discussed. The first or baseline approach utilizes composite material for the hub and hinge structures in lieu of metallic material and elastomeric bearings in lieu of wet lubricated roller bearings or Teflon-lined dry bearings. The second approach is a variant from the baseline which features a bearingless, composite material hub and hinge assembly with blade motions accommodated by flexure of tailored structural members.

(1) (U) Baseline composite hub. The baseline hub and hinge assembly features use of composite material for the center hub and pitch housings with metallic usage limited to the hub and rotor shaft interface, hinge pins, and connectors. Elastomeric bearings are used to the maximum extent possible to accommodate blade motions. The desirable characterics of the baseline include damage tolerance/fail-safe design, 10,000-hour fatigue life with weight and cost savings, and improvements in reliability and maintainability.

(2) (U) Bearingless composite hub variant. The bearingless composite hub variant is more technologically advanced than the baseline hub and hinge assembly by virtue of the substitution of tailored, composite structural elements for the primary motion bearings. Through judicious selection of structural shapes and material systems, the hub stiffness is tailored for the flapwise, chordwise, and pitching motions of each blade. These same members also react blade centrifugal force loads and transmit blade lift and rotor torque loads. Composite material permits the design of these multifunctional structural elements and the elimination of bearings.

(a) (U) The bearingless composite hub is based on the integrated technology rotor (ITR) program which integrates technological advances in the disciplines of aerodynamics, structures, materials, acoustics, and dynamics to provide improvements in such areas as rotor performance, weight, noise, reliability, maintainability, survivability, and cost.

(b) (U) One disadvantage to the bearingless hub and hinge configuration is the loss of a blade fold hinge. Reintroduction of this hinge negates some of the weight, cost, reliability, and maintainability advantages. The ITR program is scheduled to complete the first flight test in fiscal year (FY) 87.

b. (U) The baseline hub and hinge assembly is equally applicable to new aircraft and derivative aircraft since it basically represents the application of composite materials and elastomeric bearings to current design configurations. Hub and hinge assembly designs for new aircraft present fewer problems due to the greater design freedom available. Designs for derivative aircraft offer greater challenge due to the matching of dynamic and kinematic requirements; however, retrofit designs are possible.

c. (U) The bearingless composite hub and hinge configuration is applicable to all new aircraft, again, by virtue of the greater design freedom available. Application to derivative aircraft is possible but involves modification of control systems and more restrictive design due to the interdependence of structural elements.

d. (U) The primary characteristics to be described are weight and costs. A comparison of fatigue life, damage tolerance/fail safety, reliability, maintainability, vulnerability, detectability, and decontamination characteristics among the metallic, baseline composite, and bearingless composite variant hubs will be presented.

(1) (U) Weight savings of 15 percent are estimated for a baseline composite hub and hinge assembly. This is based on a completed preliminary design for a CH-47D composite rotor hub and an ongoing preliminary design for a UH-60A composite hub. The 15-percent weight savings due to composite technology is applicable to helicopter/compound, ABC, and tilt rotor LHX configurations.

(a) (U) The bearingless (ITR) composite hub technology offers a weight savings of 18 percent over the baseline composite hub. The 18-percent advanced technology weight savings is applicable to the helicopter/compound LHX configuration. The ABC and tilt rotor configurations will result in 6-percent savings over the baseline composite hub weight.

(b) (U) The ITR hub concepts do not provide for rotor blade folding. An estimated weight penalty for adding a manual blade fold to the bearingless composite variant is 0.2 percent of design gross weight.

(2) (U) Average production cost savings of 44 percent for a composite main rotor hub over a similar metallic hub were determined from a prior survey of six different composite hub designs. These three hubs do not reflect military requirements and, as such, disproportionately influence the average cost savings of 44 percent. Therefore, cost savings of 25 percent are projected for an LHX composite hub and hinge assembly. These cost savings are applicable for all proposed LHX configurations. The bearingless composite

variant is not projected to provide any additional cost savings over the baseline composite. This results in the variant having a higher cost-per-lb value than the baseline due to its lighter weight.

e. (U) The fatigue life of all hub and hinge structures can be increased if weight penalties can be tolerated. This is particularly true with metallic construction since the S-N curve (fatigue stress versus cycles to failure) for metals is relatively steep and a given reduction in stress by use of larger cross sections results in an increase in the number of permissible fatigue cycles. Composite materials, however, have a flatter S-N curve which results in greater gains in fatigue life than is characteristic of metal with similar reductions in stress levels. This material property of composites allows composite structures to be designed for higher fatigue lives with a lower percentage weight penalty than metallic structures.

(1) (U) A 10,000-hour minimum fatigue life for composite structures is readily obtainable while maintaining the weight and cost savings projected. The ITR program also has a fatigue life goal of 10,000 hours and will demonstrate the values obtainable for the bearingless composite variant. Current and planned usage of elastomeric bearings in metallic and composite hub designs predicts a fatigue life in the 4,500- to 5,000-hour range.

(2) (U) It should be noted that component fatigue life is directly related to aircraft loads and that any increases in operational envelopes will decrease service life of the hub and hinge assembly.

f. (U) With the exception of graphite, composites are extremely tolerant to impact damage. Facings of fiberglass improve the resistance of graphite to low-energy impact such as tool drops and handling damage. Ballistic damage tolerance is provided by the high strength, multiple fiber, and slow crack growth of composite materials. Fail safety is characterized by redundant load paths which are assisted by the tailorability of composite materials and by slow crack growth which allows sufficient time between the onset of a failure and its resultant affect on performance.

g. (U) The reliability and maintainability characteristics of composite hub and hinge assemblies are predicted to improve over metallic systems. Improvements in reliability are projected in the 25- to 35-percent range while maintainability improvements will be approximately 20 percent.

(1) (U) The projected mean time between repairs for composite hubs is in the 7,000- to 8,000-hour range. The lowest level of component and subcomponent removal and replacement is aviation unit maintenance (AVUM). Limited AVUM field repair, generally cosmetic in nature, will be permitted. More critical subcomponent removal and replacement actions and more extensive repair, where permissible, will occur at aviation intermediate maintenance (AVIM) level. Repair action on thickly laminated composite structures, which will be characteristic of composite baseline or bearingless hubs, will be limited, but no more so than exists on forged metallic structures. Maintainability of composite hub systems will be enhanced by a reduction in

parts count. A 45-percent reduction over current metallic technology is projected for a bearingless composite variant while a 12-percent reduction is applicable for the baseline composite hub. Composite material usage will adversely impact two areas of maintainability. Repair time will increase by an estimated 25 percent while the material cost for repair will increase by an estimated 150 percent. These factors, however, will be offset by the increased reliability, the simpler design, and the reduced parts provided by the composite hub and hinge assemblies.

(2) (U) No special skill level will be required for composite structure inspection and repair. Necessary skills can be obtained within a standard maintenance course with emphasis placed on detection and identification of defects such as cracks, debonds, and delaminations and on proper repair techniques such as surface preparation, cleanliness, mixture of adhesive systems, and application of repair material.

h. (U) Anti-icing requirements and methods for metallic and composite hubs are the same. Droop stop mechanisms are generally the only hub components requiring consideration. Electrical heaters are used to prevent ice accumulation if adequate shielding is not provided by surrounding hub structures.

i. (U) The structural properties of composite material systems degrade to a steady-state condition due to long-term exposure to heat and moisture. Once this state is reached, there is no evidence that significant additional degradation occurs. To compensate for this known condition, knockdown factors are applied to composite material strength properties during the design process.

j. (U) Lightning protection of composite structures is required due to their poor conductive properties. Integration of metallic wire mesh into the structure surface or use of braided metal jumper cables provides adequate conductive paths to prevent lightning strike damage.

k. (U) The ballistic tolerance requirement of hub and hinge assemblies to a given threat is related to the design gross weight of the aircraft due to the correlation between gross weight, hub size, and threat damage. Ballistic tolerance is defined by the ability of the aircraft to perform 30 minutes of safe flight after impact by the threat.

(1) (U) Based on the gross weight criteria of the LHX, the applicable threat tolerance is the 14.5mm armor-piercing incendiary (API). Ballistic tolerance results on aircraft with various gross weights indicate that tolerance to this threat can be achieved with a baseline composite hub. Invulnerability to the 14.5mm threat is also projected for the bearingless composite variant.

(2) (U) Depending on the specific hub and hinge design configuration selected for the LHX, limited tolerance to the 23mm API threat may be possible for a composite structure; however, tolerance to the 23mm high-explosive incendiary is unlikely.

l. (U) No increase in radar reflectivity is projected for the baseline composite approach. This assessment is valid for the bearingless composite variant since one of the ITR program goals is low drag which requires a low hub profile and smooth surface contours. The use of externally applied radar-absorbant material is equally applicable to metallic and composite construction. Composite systems, however, have the advantage because this material can be integrated into the structure during fabrication.

m. (U) Limited information is available on the decontamination of NBC contaminants, especially with respect to composite systems.

(1) (U) Active chemicals are not the only alternative cited for aircraft decontamination. A mixture of strong detergent and water can be used to wash the aircraft; however, this solution will not neutralize the active chemical contaminant. Therefore, it is necessary to decontaminate the drainage water to ensure the safety of ground personnel. Another method of decontamination involves evaporative dilution of the agent with hot air. This method is time-consuming and is not particularly effective on thickened agents.

(2) (U) Alternative paint systems for aircraft could assist the decontamination effort by providing a hard, nonporous surface. Such a system is polyurethane paints which have been developed and are being applied to Army aircraft. The previously used alkyd paints absorb high levels of contaminating chemicals which continually out-gas even after surface decontamination.

N-II-9. (U) RELATED IMPLICATIONS ON ROTOR HUBS.

a. (U) Schedule Consideration. Metallic technology for rotor hubs has been fully demonstrated for helicopter/compound, ABC, and tilt rotor technology. The baseline composite approach is in the early stages of complete development for commercial aircraft, with military applications lagging.

b. Risk. Metallic hub and hinge assemblies present a low risk based on the existing development of the UH-60, AH-64A, XV-15, and XH-59A. The baseline composite approach is assessed to have a low to moderate risk for the LHX due to the lack of demonstrations planned for military aircraft. The bearingless composite variant approach has a moderate risk because it is based on emerging ITR designs. A general risk assessment of the ITR program is provided in figure N-II-12. In addition to the ITR program demonstration of bearingless designs, past efforts have demonstrated the feasibility of the concept. The UH-60A and the YUH-61A both use bearingless composite tail rotors. A composite flexbeam tail rotor has been developed for the AH-64A and has performed successfully in full-scale wind tunnel testing. The Army's composite bearingless main rotor was first flight tested in 1978, and Bell flight tested their model 680 bearingless composite rotor in early 1983.

Area	Risk
Management	
Program cost	Low
Program schedule	Medium to high
Technical	
Producibility	
Current technology	Low
Automated technology	High
Overall performance	Medium
Characteristics	
Improved rotor performance	Medium
Reduced noise	High
Reduced radar cross section	Medium
Reduced maintenance	Low
Increased reliability	Low
Weight savings	Low
Cost savings	Low
Structural design criteria	Medium

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Figure N-II-12. (U) ITR program risk assessment.

c. (U) TMDE. No special test or diagnostic equipment beyond that currently used for metallic systems is required for the composite baseline or variant approaches. Necessary equipment is related to hub and hinge track and balance requirements. Compliance with these requirements does not require field or in-flight testing. Ultrasonic C-scan inspection equipment will be required for AVIM and depot-level maintenance of composite structures.

d. (U) Training. Composite structure fabrication, inspection, and repair methods will need to be incorporated into standard aircraft maintenance courses. Emphasis will be placed on detection and identification of defects such as cracks, debonds, and delaminations and on proper repair techniques such as surface preparation, cleanliness, mixture of adhesive systems, and application of repair material.

e. (U) ILS. ILS will be favorably impacted by the reduction in parts provided by composite hub and hinge designs. The bearingless composite variant, with its lower part count, will be easier to support than the baseline composite approach.

f. (U) RSI. The technical impact of achieving RSI objectives on metallic or composite hub and hinge assemblies is equal. Standardization of components is not feasible due to the unique design of all hub and hinge parts. The RSI goal of fostering technological transfer must be made as a deliberate choice since the ITR program appears to be leading the European effort with respect to advanced or bearingless rotor hub technology.

g. (U) Producibility. The materials used for metallic hub structures are steel, aluminum, and titanium with the latter being a critical material. Composite hubs rely primarily on fiberglass and graphite fiber systems with limited use of Kevlar due to its unfavorable compressive strength characteristic. Epoxy resin systems are used as the matrix material to bind the composite fibers into an integral structure. Storage of these preimpregnated composite materials, both before and during the fabrication process, requires large refrigeration units to prevent degradation of the resin systems.

(1) (U) The workability of steel and aluminum is well known. Machining of titanium is a slow, critical process and results in large scrapage rates. Methods of casting acceptable titanium hub components have been unsuccessful. Composite fabrication techniques allow production of net to near-net components within curing tools, while at the same time incorporating complex curvature and redundant structural elements. This ability to integrate redundant and subcomponent elements results in the reduction of parts over metallic fabrication methods. Composite material systems are readily machined and drilled.

(2) (U) The skill level necessary for composite hub production is less than that required for skilled machinists due to the relatively simple layup and assembly procedures which are jig- or mold-controlled. Quality control of material-handling and curing processes is critical. However, the standards for these are well established and adherence does not require a high level of skill.

N-II-10. (U) RECOMMENDED ALTERNATIVE ROTOR HUB SYSTEMS.

a. (U) The matrix (figure N-II-13) provides a qualitative comparison of the characteristics of the baseline composite and bearingless composite variant approaches as compared to UH-60A/AH-64A metallic hub and hinge technology.

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Characteristics	Candidate System: Baseline Composite	Candidate System: Bearingless Composite
Weight		X
Cost		
Fatigue life		
Damage tolerance/fail safety		
RAM		X
Vulnerability		
Decontamination		
Schedule	X	
Risk	X	
TMDE		
ILS		X
RSI		

X means superior performance or capability.

Figure N-II-13. (U) Evaluation of hub and hinge alternatives.

b. (U) The baseline composite hub and hinge approach shows a clear advantage over metallic structures. The bearingless composite variant provides some improvement over the baseline; however, increased risk is evident.

c. (U) The recommended alternative for the hub and hinge assembly is the bearingless composite variant. The weight, reliability, and maintainability advantages of this approach make the increased risk acceptable. The reason for adverse risk is the dependence of this approach on the completion of the ITR program for technical demonstration. It should be noted that the ITR program should provide aeromechanic and performance benefits that cannot be addressed at this time. The bearingless composite variant is applicable to all LHX configurations.

d. (U) The baseline composite approach will provide a safe fall-back position. However, the bearingless composite hub is recommended due to projected technological advances and operational benefits that will accrue from technology that will occur in the mid-1980s.

N-II-11. (U) ROTOR BLADES. This section will discuss main rotor blades. Current tail rotor technology features a bearingless composite design with the hub and blade integrated and will not be discussed.

a. (U) Description of Alternative Approaches. Two primary approaches for the rotor blade structure will be presented. The first or baseline approach utilizes composite material for the spar and skins. The second approach is a variant from the baseline which features composite skins and a metallic spar.

(1) (U) Baseline composite blade. The baseline rotor represents complete composite material construction with metallic components limited to leading edge and tip weights, blade attachment cuffs or lug bushings, tip weight housings, and sometimes leading edge erosion strips. Spar and skin material systems include the three principal fiber/epoxy systems of fiberglass, graphite, and Kevlar, used either individually or interlayered. Because rotor blades are stiffness-critical structures with minimum weight requirements for proper autorotation characteristics, matching of geometric constraints and composite material properties is more critical than achieving a minimum strength requirement. The high strength characteristics of composite materials result in designs with unlimited fatigue life. Other desirable characteristics include damage tolerance/fail-safe design, cost savings, and improvements in reliability and maintainability.

(2) (U) Metal variant blade. The metal spar blade variant uses skin material systems similar to those used on the baseline blade and the same metallic components except that the structural spar element is of stainless steel, aluminum, or titanium rather than composites. High fatigue lifes are achievable with these designs; however, the relatively fast crack propagation rate within metals, especially titanium, requires special consideration to ensure the metal spar maintains its structural integrity. This feature also results in less damage tolerance for the variant approach. The variant blade approach represents a lower level of technology than does the baseline.

b. (U) Application to New/Derivative Aircraft. Both the baseline composite and the metallic spar variant are equally applicable to new or derivative aircraft. Retrofitting the baseline blade to replace completely metallic rotor blades has already been accomplished for some inventory aircraft. These retrofits also incorporated improved rotor blade performance features while maintaining dynamic and geometric compatibility with the existing metallic hub and hinge assembly.

c. (U) Operational Characteristics.

(1) (U) The primary characteristics to be described are weight and costs. A comparison of fatigue life, damage tolerance/fail safety, reliability, maintainability, vulnerability, detectability, and decontamination characteristics among the metallic, baseline composite, and metallic spar variant will also be presented.

(2) (U) In general, no weight savings are projected for the helicopter/ compound LHX blade configurations. This is due to the dynamic requirements imposed on blades which require minimum weights for proper autorotation characteristics. These requirements exist for all-metallic blades, metallic spar blades, and all-composite blades. For blades which employ a metallic cuff for blade attachment, 8-percent weight savings are possible with the composite design. This results from modification of the root end area by incorporating filament winding pin wrap techniques into the blade design rather than utilizing the externally mounted metal cuff.

(3) (U) Five-percent weight savings are projected for the baseline composite blade over an all-metallic or metallic spar blade for the ABC and tilt rotor LHX configurations. These savings can be realized for these aircraft since the blade designs are not controlled by autorotation requirements. No additional weight savings are projected for modified root end configurations since cuffed designs are not applicable to these blades.

(4) (U) The blade trend weights reflect a manual blade fold for the helicopter/compound configuration. Incorporation of a manual blade fold into the ABC and tilt rotor blades results in a 3-percent weight penalty. For a powered blade fold, a 30-percent weight penalty must be imposed on the manual fold helicopter/compound and nonfolding ABC and tilt rotor blade weights. These weight penalties are taken as a percentage of blade weight. However, the additional structural weight is actually added to the hub and hinge assembly.

(5) (U) Recent blade designs are more aerodynamically complex than earlier designs and are more economically produced with composites than with metals. Information from a current manufacturing study of baseline composite blades indicates 33-percent savings are attainable with a precured composite spar concept and 38-percent savings can be achieved if a co-cured composite blade concept is employed. These savings are based on an existing metallic spar blade which uses composite skins. Therefore, as a conservative estimate, the baseline composite approach will provide 35-percent production cost savings over the metallic or metallic spar variant approach.

(6) (U) The fatigue life of all current-technology baseline composite blades is unlimited. The fatigue life on all-metallic blades has generally been in the 1,100- to 2,500-hour range based on retirement lives. Due to the fatigue strength characteristics of composite materials, the cost savings and unlimited fatigue life attainable without any physical weight penalty make the baseline composite more desirable.

(7) (U) With the exception of graphite, composites are extremely tolerant of impact damage. Facings of fiberglass improve the resistance of graphite to low-energy impact such as tool drops and handling damage. High-energy impact tolerance is improved by combining fiberglass or Kevlar with graphite. Ballistic damage tolerance is provided by the high strength, multiple fiber, and slow crack growth of composite materials. Fail safety is characterized by redundant load paths which are assisted by the tailorability of composite materials. These characteristics of composite structures provide a safer component than metal while achieving cost savings.

(8) (U) Some improvement from the implementation of a composite rotor blade should result from: (1) improvements in reliability, (2) inherent reliability, and (3) increased tolerance to the operational environment.

(a) (U) Damaged metallic blades generally reflect little or no field repairability and, as a result, are shipped to depots for repair and adjustment. Composite blade afterbody repairs and adjustments have been satisfactorily performed during formal maintenance demonstrations. The inherent reliability of the composite blade structure results from fewer problems such as debonding and corrosion and, when coupled with increased tolerance to damage from the operational environment, extends blade life, decreases aircraft downtime, and lowers spare requirements (see figure N-II-14).

(b) (U) In addition to the increased repair time shown for composites, an increase of approximately 150 percent will occur in the material costs for repair. These two adverse factors, however, are offset by the significant decreases in maintenance actions at the AVUM and AVIM levels and in failure rates.

(9) (U) The radar cross section signature reduction could be over 90-percent for a composite blade as compared to a current metallic blade. Such a radar reduction was demonstrated on a multi-tubular spar composite blade. Also, the use of radar-absorbant material is equally applicable to metallic and composite blades. Composite systems, however, have the advantage that such material can be integrated into their structures during fabrication.

(10) (U) A potential detection indicator has been identified with rotor blades operated in hot, dry, and dusty environments. A static charge builds on the blades with its discharge creating electromagnetic interference with onboard systems. The discharge is also detectable by ground sensors. A visual "halo" effect is also evident. The occurrence of the phenomena appears most prevalent on all composite or composite skin blades. In that existing lightning protection systems on these blades do not appear to be providing an adequate discharge path, as would be expected, the extent of this problem is

Reliability and Maintainability Consideration	Type Construction		Percentage of Change from Metallic
	Metallic	Composite	
Failure rate*	130.2	39.6	69.6 decrease
AVUM repair rate*	33.6	27.5	18.2 decrease
AVUM MMH per maintenance action	2.2	3.5	59.1 increase
AVUM MTTR	1.3	1.9	46.2 increase
AVIM repair rate*	96.6	12.1	87.5 decrease
AVIM MMH per maintenance action	1.2	2.4	100.0 increase
AVIM MTTR	.9	2.4	167.0 increase

*Per 10,000 flight hours

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Figure N-II-14. (U) Predicted reliability and maintainability characteristics for main rotor blades.

not well understood. New composite blade designs will require features to ensure prevention of the static charge buildup. Potential methods include modification of current lightning protection systems or thin metallic coatings on the blade surface. Either of these methods will have negligible impact on blade weight or cost; however, their individual effectiveness will require further evaluation. Their respective impacts on radar cross sections must also be considered.

(11) (U) Sand and rain erosion protection is required for the leading edge of metallic, metallic spar, and composite blades. Erosion protection is usually provided on the outer two-thirds of the blade radius because of the higher velocities encountered; however, full-length protection systems are not uncommon. Composite blades require protection against lightning strikes due to the poor conductive properties of composite materials. Several acceptable methods are available. All of these methods, when properly designed, can meet the single-strike, 200,000-ampere criteria, and some methods have demonstrated multiple-strike tolerance.

(12) (U) The aerodynamic configuration of the rotor blade is a trade of chord, tip speed, airfoil section, and twist distribution for the hover and forward flight regimes. Composite blades can be formed into complex shapes as economically as simpler shapes. Although metallic blades can also be made into complex shapes, the practical, economical constraints of forming metals, such as by extrusion, limit the potential for extensive tapering, spanwise airfoil changes, or complex tip geometries. The ability to incorporate these design features permits a more efficient tailoring of aerodynamic (airfoil) sections along the blade span and transitioning from one airfoil section to another. Significant performance improvements in both the hover and forward speeds are projected through aerodynamic tailoring. Composite blades can also easily incorporate high blade twists which result in improved hover efficiency. The high strain allowable of composites (twice that of aluminum) can accommodate the increased blade loads associated with a highly twisted distribution. The higher structural efficiency of the composite material also allows a wider chord blade of equivalent weight to a metallic blade.

(13) (U) Due to the fully developed nature of the baseline composite blade, there is no risk to the LHX.

(14) (U) No special test or diagnostic equipment, beyond that currently used for metallic and metallic spar blades, is required for the baseline composite blade. Necessary equipment is related to blade track-and-balance requirements. Compliance with these requirements is achieved using well-defined test and diagnostic procedures.

(15) (U) Composite structure fabrication, inspection, and repair methods will need to be incorporated into standard aircraft maintenance courses. Emphasis should be placed on detection and identification of defects such as cracks, debonds, and delaminations and on proper repair techniques such as surface preparation, cleanliness, mixture of adhesive systems, and application of repair material.

(16) (U) ILS will be favorably impacted by the reduced failure rate of the baseline composite blade.

(17) (U) The technical impact of achieving RSI objectives on metallic or composite main rotor blades is equal. Standardization of components is not feasible due to the unique design of all rotor blade parts.

(18) (U) Composite fabrication techniques allow production of net to near-net components within curing tools while at the same time incorporating complex curvature and redundant structural elements. This ability to integrate redundant and subcomponent elements results in the reduction of parts over metal fabrication methods. Graphite/epoxy and fiberglass/epoxy systems are readily machined and drilled when necessary.

(19) (U) The skill level necessary for composite hub production is less than that required for skilled machinists due to the relatively simple layup and assembly procedures which are jig- or mold-controlled. Quality

control of material-handling and curing processes is critical; however, the standards are well established and adherence does not require a high level of skill.

N-II-12. (U) RECOMMENDED ALTERNATIVE ROTOR SYSTEMS. Figure N-II-15 provides a qualitative comparison of the operational characteristics of the baseline composite and the UH-60A/AH-64A metallic spar variant approaches. The recommended alternative for the main rotor blade assembly is the baseline composite which features all composite construction. The fatigue life and reliability and maintainability advantages of this approach, combined with its complete operational demonstration, make it the clear choice.

N-II-13. (U) LANDING GEAR STRUCTURES.

a. (U) The UH-60/AH-64 metallic technology forms the baseline to evaluate landing gear design criteria. Both of these helicopters were designed to crash criteria which were less stringent than the current Military Standard (MIL-STD) 1290, Light Fixed and Rotary Wing Aircraft Crashworthiness. The basic landing gear requirements for UH-60/AH-64 aircraft and modified versions of MIL-STD 1290 are presented in figure N-II-16. The original UH-60 was designed to meet two primary vertical sink speed conditions: (1) a 15-feet per second (feet/sec) $\pm$10-degree ($^\circ$) roll without fuselage contact and (2) a 42-feet/sec 0° roll and pitch where the landing gear, in combination with stroking seats and crushable subfloor structure, would attenuate energy as a system to provide a survivable crash. The UH-60 landing gear did not meet the second condition and the system requirement was subsequently relaxed to 35 feet/sec. The AH-64 landing gear met all of its requirements as outlined. The UH-60 and AH-64 possess three-point tail wheel landing gear arrangements which attach to various hardpoints of the airframe, such as bulkheads, frames, and beams. Both landing gear designs have two-stage shock struts connected in series which provide energy attenuation during a crash.

Characteristics	Baseline Composite	Metallic Spar Variant
Weight		
Cost	X	
Fatigue life	X	
Damage tolerance/fail safety	X	
Reliability and maintainability	X	
Vulnerability	X	
Decontamination		
Schedule		
Risk		
TMDE		
ILS	X	
RSI		

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X indicates better or superior attribute.

Figure N-II-15. (U) Blade candidate systems.

	MIL-STD 1290	UH-60	AH-64	ACAP	Advanced Technology Landing Gear
Gear impact conditions (no fuselage contact)	20 feet/sec ±10° roll ±10° pitch	15 feet/sec ±10° roll	24 feet/sec ±12° roll ±15° pitch	20 feet/sec ±10° roll ±10° pitch	20 feet/sec ±10° roll -5° to +15° pitch
Aircraft impact conditions	42 feet/sec ±30° ±15°	38 feet/sec ±10° roll	42 feet/sec 0° roll 0° pitch	42 feet/sec ±10° roll -5° to +10° pitch 36 feet/sec ±20° roll -15° to +20° pitch UNCLASSIFIED	42 feet/sec ±5° roll -5° to +15° pitch ±10° roll -5° to +10° pitch 36 feet/sec ±10° roll -10° to +20° pitch ±20° roll -5° to +10° pitch

Figure N-II-16. (U) Landing gear requirements.

b. (U) Advanced landing gear technology is being developed under two programs. The first program is part of the ACAP where two fixed landing gears are being developed to meet the design requirements of a modified MIL-STD 1290. Both tricycle and tail wheel configurations, employing trailing arms with oleo shock struts, have been designed. The gears were developed using predominantly UH-60/AH-64 metallic technology. The only exception to this was that one of the designs incorporated graphite/fiberglass composite materials as an energy attenuator in addition to the two-stage stroking energy absorption feature.

c. (U) The second program is a two-phase development program directed ultimately at designing, fabricating, and testing a retractable landing gear for an LHX-sized aircraft. The first phase involves the preliminary design of three landing gear configurations to normal operating and crash conditions. The designs feature noncrashworthy retractable, crashworthy retractable, and crashworthy fixed landing gear and incorporate the use of composite materials to provide weight savings. The preliminary designs will provide a trade-off for both crashworthy fixed and retractable designs and will provide a sensitivity analysis of how retractability and the use of advanced composite materials affect overall aircraft performance, reliability, maintainability, and cost. The second phase will be directed at fabricating and testing the selected retractable design to verify structural integrity.

d. (U) A description of the UH-60 and AH-64 landing gears is given in paragraph N-II-13a. These were the first Army helicopters designed for crashworthiness. The wheel aligning gear configurations give superior ground handling over conventional skid arrangements. Both gears have demonstrated the capability to absorb at least 50 percent of the energy in a survivable crash. The UH-60 and AH-64 landing gears function without failure at vertical impacts of 30 feet/sec and 31 feet/sec, respectively. Use of these existing systems is certainly a viable approach for derivative landing gear variants.

e. (U) Both ACAP helicopters (D-292 and S-75) have been designed for crashworthiness and can be reconfigured to accommodate additional troops and a retractable crashworthy landing gear, while still keeping the gross weight in the range of 8,000-9,000 lb. The D-292 landing gear employs a two-stage, oleo shock strut connected in series and a graphite/fiberglass tube cutter which absorbs additional energy. This three-point tail gear arrangement is a trailing arm, fixed wheel-type landing gear which has been designed to absorb vertical impact velocities of 34 feet/sec (65 percent of the energy in a 42-feet/sec vertical crash). The S-75 landing gear is a tricycle wheel, two-stage, oleo shock strut configuration with both stages of the shock strut connected in series. The S-75 landing gear has been designed to absorb vertical impact velocities of 35 feet/sec (70 percent of the energy in a survivable crash). Since both ACAP helicopters have been designed to the crash criteria as presented in figure 16, they have provisions in the airframe for a crushable subfloor structure and stroking seats.

f. (U) The HH-65A (SA-366) landing gear is a tricycle, retractable wheel-type arrangement featuring a single-stage, oleo pneumatic shock strut design. The gear retracts rearward into the lower portion of the fuselage.

Fairings enclose the main gear wheel wells after retraction, which is accomplished hydraulically. Provisions are made for emergency extension of the gear. This arrangement was designed to normal operating conditions of 10 feet/sec at a 2° roll and a reserve energy condition of 12.25-feet/sec vertical sink speeds. The airframe does not have a crushable subfloor structure. A 30-feet/sec gear and a modified airframe with stroking seats are required to achieve the Black Hawk level of crashworthiness.

g. (U) The A-129 main landing gear is a fixed tail wheel configuration. Each gear is equipped with two-stage, energy-absorbing, hydraulic shock struts. The lower stage limits vertical sink speed to 10 feet/sec (15 feet/sec for hard landings), and the upper stage operates only for crash landings. The gear is designed to decelerate the aircraft from a vertical impact velocity of 15 feet/sec without fuselage contact. Additionally, the gear is designed to prevent it from being driven into the fuel tank or into occupied cabin space. The tail landing gear is designed for hard landings up to 15 feet/sec and a nose-up pitch of 30°. The airframe has a crushable subfloor structure with high-mass items designed to be retained upon impact. This helicopter is designed to the 90th percentile of MIL-STD 1290 but is below the Black Hawk level of crashworthiness.

N-II-14. (U) CHARACTERISTICS OF METALLIC AND COMPOSITE CONSTRUCTION TECHNIQUES TO ASSESS WEIGHT, COST, AND PRODUCIBILITY.

a. (U) Metallic Construction, Fixed Gear, UH-60/AH-64. The major components fabricated for these landing gears include outer cylinders, pistons/axles, rotation collars, torque arms, and drag braces. These components are typically manufactured from high-strength steel and aluminum forgings and are machined to come within tolerance of the parts. Since extensive machining is required, much of the machined material becomes scrap waste. Besides high scrap rates, the machining of these parts becomes very labor intensive. After the parts are machined, the components are shot-peened and polished. As can be readily seen, the manufacture of landing gears is expensive. The use of high-strength steel imposes weight penalties, as do additional parts to provide for a second-stage, energy-absorbing device to meet this level of crashworthiness.

b. (U) S-75 Landing Gear. One of the ACAP landing gears (S-75) has been designed to a modified version of MIL-STD 1290. Since this level of crashworthiness is more stringent than the UH-60/AH-64 level, the gear is more massive and subsequently weighs more to meet these criteria. It is estimated that a 15-percent weight and cost increase in the UH-60 level of crashworthiness is needed to bring that gear to meet the requirements of a modified MIL-STD 1290. This landing gear has the same producibility as the UH-60/AH-64.

c. (U) Derivatives. The fixed, noncrashworthy wheel gears are lighter in weight due to the elimination of the second stage and are less massive, also contributing to the weight reduction, because they are designed to normal operating conditions. The cost is also reduced due to a reduction in parts count, and less machining is required because of smaller forging requirements.

These gears are more producible than the UH-60/AH-64 gears because labor is reduced. It is estimated that a 23-percent weight and cost increase would bring these gears up to the UH-60/AH-64 level of crashworthiness. Only the A-129 crashworthy landing gear would compete with the UH-60 and AH-64 gears on cost, weight, and producibility bases.

d. (U) Metallic Retractable Gear, UH-60/AH-64. No retractable landing gears have been designed and fabricated to this level of crashworthiness. A weight increase of 10 percent is likely due to additional parts required to retract the gear and added space requirements which would require airframe modifications. The increased parts count as well as the complexity of retraction mechanisms would raise the cost approximately 10 percent over the fixed metallic design. The producibility would be the same since all the equipment for tools and fabrications is readily available.

e. (U) Metallic Retractable Gear, MIL-STD-1290. A retractable metallic landing gear has not been fabricated to a modified version of MIL-STD 1290. In designing for a higher level of crashworthiness, greater weight and cost are associated with the more massive gear. It is estimated that a 15-percent increase in weight and costs would result in designing a retractable gear to these criteria, as opposed to designing a retractable gear to the UH-60/AH-64 level.

f. (U) Derivatives. The HH-65A is the only retractable-wheel landing gear of the derivatives discussed. Since this is not a crashworthy gear, the weight is 23 percent less than a metallic, crashworthy, retractable gear which was designed to the UH-60/AH-64 level of crashworthiness. The cost would be approximately 23 percent less due to the reduced tooling, machining, and material costs required to fabricate a smaller landing gear arrangement. This gear is more producible than a UH-60/AH-64 retractable landing gear.

g. (U) Composite Construction, Fixed Gear, UH-60/AH-64. The design of a gear to meet this level of crashworthiness could incorporate advanced materials which include polymer matrix composites such as graphite, fiberglass, and Kevlar/epoxy or metallic matrix composites such as silicon carbide/aluminum and silicon carbide/titanium. Using advanced composite materials and manufacturing techniques, it is estimated that 5-percent manufacturing cost savings would be realized over a UH-60/AH-64 fixed, metallic gear. Thirteen-percent weight savings are also possible which would result in greater aircraft performance, reduced reliability and maintainability, and reduced life cycle costs. These savings are based on utilizing epoxy matrix composites. The producibility of this gear would be better than a UH-60/AH-64 metallic, fixed landing gear.

h. (U) Model 292 ACAP Gear. A landing gear program exists where the ACAP landing gear was designed to a modified version of MIL-STD 1290. The model 292 ACAP landing gear includes an additional energy-attenuating device in conjunction with the two-stage shock strut. In comparison with the fixed composite, UH-60/AH-64 landing gear, the ACAP landing gear using the composite construction techniques would weigh approximately 15 percent more due to the

more stringent crash design criteria. The corresponding increase in costs would be approximately 15 percent. It is assessed that both gears discussed herein are equally producible.

i. (U) Derivatives, Composite, Fixed. Wheel landing gears designed to normal operating conditions would probably have more applications for composites than exist for the UH-60/AH-64 level of crashworthiness. The manufacturing techniques would be the same. Utilizing composites would provide approximately 15 percent in weight savings and 7.6 percent in cost savings over a metallic, noncrashworthy, fixed wheeled landing gear but little, if any, increase in crashworthiness.

j. (U) Retractable Gear, Composite, UH-60/AH-64. No retractable landing gears have been designed and fabricated from composites to this level of crashworthiness. A weight penalty of 10 percent would result from additional parts required to retract the gear and added space requirements which would require airframe modifications. Thirteen-percent weight savings would be gained over the metallic, retractable gear utilizing composites. Hence, 3-percent overall weight savings would result over the metallic, fixed UH-60 gear. The increased parts count as well as complexity of retraction mechanisms would increase the cost over the fixed, metallic design by approximately 4 percent. Both gears are assessed to be equally producible.

k. (U) Retractable Gear, Composite, MIL-STD-1290. A retractable landing gear utilizing composites has not been fabricated to a modified version of MIL-STD 1290 as yet. A developmental program is underway to design, fabricate, and test an advanced technology landing gear designed to these crash criteria. Because these criteria are more stringent than those of UH-60/AH-64 composite retractable designs, greater weight and costs are associated with the more massive gear. The weight and cost increases are approximately 15 percent. Both designs are equally producible.

l. (U) Derivatives. The HH-65 was the only derivative helicopter with a retractable gear. Utilizing composites would provide weight savings but little, if any, increase in crashworthiness due to the nature of the single-stage shock strut design. The weight advantage gained using composites over a fixed, metal gear is approximately 15 percent. A weight penalty of 10 percent would be required for retraction, so a resulting 5-percent weight reduction exists for fabricating a retractable, composite, noncrashworthy landing gear over a metallic, noncrashworthy, fixed gear. The retractable design costs more than the fixed design due to the complexity of the retraction mechanism.

N-II-15. (U) OTHER CONSIDERATIONS. The effect of other considerations on the primary characteristics for landing gear are discussed below:

a. (U) Damage Tolerance/Fail Safety. Since damage tolerance is a function of material selection and design methodology, any attempt to increase the damage tolerance of metallic wheel landing gears utilizing the same materials would increase the weight and costs of these components. The effect of increasing the weight will reduce the operating stresses for these components in both normal operating and crash conditions. These changes should not

affect producibility. The damage tolerance of graphite/epoxy, on the other hand, is better than steel because surface and subsurface cracks propagate slowly as compared with steel. Metallic matrix composites also have the potential for replacing steel components. If this were done, the damage tolerance would increase and the weight would decrease, but the fabrication cost would be much higher. It is, therefore, assessed that the use of polymer matrix composites when applied to certain steel and aluminum components has the potential for increased damage tolerance, reduced costs and weight, and a higher degree of producibility than metallic wheel landing gears. This rationale applies to all wheel landing gear systems discussed.

b. (U) RAM. Crashworthy gears require more maintenance than noncrashworthy helicopter gears due to the additional parts required and their complexity. Additional maintenance is required for retractable, metallic designs for the same reasons. Maintenance can be somewhat improved, utilizing composites in both noncrashworthy and crashworthy designs, due to the reduced inspection intervals. The repair of components which lend themselves to composites can be done in an expeditious manner by an unskilled workman. Repairability of steel or aluminum components requires having an inventory of spare parts or cannibalizing a damaged aircraft. The advantages of utilizing composites are the corrosion-resistant properties they possess over metals as well as improved fatigue characteristics.

c. (U) Vulnerability Considering Ballistics, NBC, Lasers, and Lightning. All fixed, noncrashworthy and crashworthy systems are vulnerable to the above threats due to the fact that these landing gear systems are exposed outside the airframe. The noncrashworthy wheel landing gear systems are less vulnerable to the other threats due to the elimination of the second-stage shock strut, thereby reducing the extension of the gear below the fuselage. All retractable systems sealed with doors have the least vulnerability when the gears are retracted. In this mode, they become an integral part of the airframe and, therefore, have the same vulnerability as the airframe.

d. (U) Detectability. The solution to reducing radar cross sections in the past has been to aerodynamically shape portions of the aircraft in order to reduce radar cross sections, or to incorporate the internal use of radar-absorbing material in the components most susceptible to detectability from radar. In reducing the radar signature of a fixed landing gear, these solutions cannot be incorporated because they would presumably have adverse affects on the strength of the gear. An alternative approach would be to apply an external radar-absorbing coating. These systems are costly and add weight. The producibility of the fixed gears would be reduced by applying these external coatings. The detectability of retractable gears, with the gear retracted, is not a problem as long as the gear is retracted completely into the fuselage. If the gear is partially extended so as to provide some energy attenuation in the retracted mode, a fairing incorporating radar-absorbing material can completely reduce the radar signature without adversely affecting cost, weight, or producibility.

N-II-16. (U) DESCRIPTION OF THE RECOMMENDED ALTERNATIVE.

a. (U) A ranking of the candiiate landing gear configuration with respect to achieving overall system characteristics is provided below:

<u>Landing Gear Configurations</u>

(1) (U) Composite, fully retractable, wheel landing gear.

(2) (U) Composite, partially retractable wheel landing gear enclosed with fairings.

(3) (U) Composite, fixed wheel landing gear.

(4) (U) Metallic, fully retractable wheel landing gear.

(5) (U) Metallic, partially retractable wheel landing gear enclosed with fairings.

(6) (U) Metallic, fixed wheel landing gear.

b. (U) In ranking the candidate configurations, it was determined that the most desirable landing gear configuration in terms of weight, cost, producibility, drag, damage tolerance, and RAM was the composite, fully retractable wheel landing gear. It was further assessed that the estimated 13-percent weight savings gained through the utilization of composite makes this configuration the most competitive. The configuration has a drawback in that it is the least survivable if a crash were to occur with the gear in the fully retracted mode. However, in an emergency, the automatic extension mechanism would extend the gear at least partially to provide some energy attenuation.

c. (U) Should composites not provide the weight savings needed to overcome the weight penalty imposed due to retractability, a metallic, fully retractable wheel landing gear would be the most likely candidate to achieve overall system characteristics. Though a 10-percent weight and cost penalty is imposed over the fixed wheel gear design, it is anticipated that the reduction in drag, vulnerability, detection, and decontamination would offset these penalties. Additionally, no difference in engineering characteristics for the helicopter, compound helicopter, ABC, and tilt rotor exists.

N-II-17. (U) FINDINGS: AIRFRAME STRUCTURES.

a. (U) The use of composite materials and construction techniques is equally applicable to all five LHX configurations.

b. (U) The preferred approach is the maximum practical application of advanced composite materials to the LHX airframe due to significant weight, cost, durability, and detectability advantages.

c. (U) The preferred approach for the hub and hinge assembly is the bearingless composite variant due to weight, reliability, maintenance, aero-mechanical, and performance benefits.

d. (U) The all-composite rotor blades are preferred over the metallic spar variant as costs, fatigue life, damage tolerance, aerodynamic tailoring, and reliability are inherent factors of the composite blade. However, the weight of the composite rotor blade cannot be reduced as certain mass properties must be present to maintain autorotational characteristics.

e. (U) The most desirable landing gear configuration in terms of weight, costs, producibility, and drag is the fully retractable wheel landing gear of composite construction.

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ANNEX III TO APPENDIX N

LIGHT HELICOPTER FAMILY (LHX) DEPLOYABILITY (U)

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ANNEX III TO APPENDIX N

LIGHT HELICOPTER FAMILY (LHX) DEPLOYABILITY (U)

N-III-1. (U) LIGHT HELICOPTER FAMILY (LHX) DEPLOYABILITY. This portion of the TOA report discusses LHX alternatives for self-deployability, air transportability, ship transportability, and shipboard operations. Although the LHX-Scout/Attack (SCAT) is a relatively small aircraft (compared to the AH-64A) and that would tend to imply easy transportability, the mission equipment package (MEP) is extensive and sensor locations, coupled with designing for crew accommodation, rotor clearances, etc., dictate a height requirement which complicates rapid load/off-load for air transport.

N-III-2. (U) SELF-DEPLOYABILITY. The LHX Systems Attributes Document (SAD) calls for the LHX to be self-deployable for 740 nautical miles (nm) (plus 10-percent reserve fuel) for the baseline configuration, with a desired ferry range of 1,240 nm (South Atlantic route). The SAD further requires a 99-percent (.99) probability of success. The 2,100-nm Pacific mission is also discussed but not specified in the SAD.

a. (U) There are three low-risk and one high-risk approaches to be discussed. All three low-risk approaches have been tested and performed on other model rotary wing aircraft (via the 740-nm Northern Atlantic route) in the past. The one high-risk approach (in-flight towing) has been proposed but has never been fully tested over long distances. The first option is to incorporate integral fuel tanks to permit the LHX to fly the 740-nm or 1,240-nm ferry mission without modification. The second option is to provide internal and auxiliary fuel tanks to yield the extra fuel required for the ferry missions. The third option is to add provisions for an air-to-air refueling kit. The final option (high-risk) is to add provisions to the LHX for in-flight towing, at least on the long length mission legs, by another aircraft.

(1) (U) Internal tank capacity. While this option is simple and obvious, it requires space and weight on all configurations that could be used for other subsystem component installations. Additionally, the extra tank capacity (unused except during a ferry mission) absorbs space needed for armament, avionic components, and, in the utility variant, passenger/cabin space. Also, the large tank capacity requires support structure to incorporate a crashworthy fuel system which would consume valuable weight needed elsewhere. It is felt that, regardless of the LHX baseline configuration, the built-in internal tank capacity option is not viable with the possible exception of the 740-nm mission for the tilt rotor configuration.

(2) (U) Auxiliary fuel tanks. The use of auxiliary tanks is by far the most common method of range extension used on current vertical take-off and landing (VTOL) aircraft models. Where cabin space exists, bladder-type fuel cells can be added with integral fuel transfer fittings and pumps to

shift the fuel into the aircraft main tanks as required. For LHX-SCAT configurations, externally attached, aerodynamically clean tanks can be attached to the sides of the fuselage or, in the case of the tilt rotor configuration, under existing wings.

(3) (U) Air-to-air refueling. This option would use proven, existing technology to add an in-flight refueling probe either permanently or as a kit. However, there are permanent additions required to the aircraft hydraulic or pneumatic subsystems along with probe extension/retraction control systems. Operational use requires extensive coordination with the US Air Force (USAF) for refueling tanker aircraft linkup. If Army aviation units were routinely rotated to overseas areas, this option would appear more attractive.

(4) (U) In-flight towing. The concept would require structural design to provide a tow-point on the front of the LHX and tow-cable linkup/delink hardware and control. The operational concept would be to have one large (e.g., C-130) tow plane linkup and tow two or more LHX-sized aircraft overseas. Once linked up, the LHX aircraft could reduce power (or shut down the main engine(s)) and autorotate. The drive train must continue to provide onboard generation of electrical and/or hydraulic power as would be necessary for flight control and other subsystem operations. This concept, using a ground hookup, was tested in a very rudimentary manner in the 1950s and 1970s. It must be considered to be high-risk and in need of extensive development and testing. No such plans for concept development are known to exist at present.

b. (U) The US Navy (USN) has a wide variety of surface craft with some form of landing platform on the deck. In addition to 15 aircraft carriers, 5 landing helicopter assaults (LHA), and 7 landing platform helicopters (LPH), the USN has approximately 209 ships with a certified aviation platform/turbine engine refuel capability, and about 113 of these have a certified helicopter in-flight (hover) refuel capability. Positioning of a specific number of these ships at strategic points along any of the deployment routes could form a refueling "bridge" for basic, unmodified LHX aircraft. This option is deemed least viable since at-sea landing and/or in-hover refueling success is highly dependent on the weather and/or sea conditions. Only the larger deck ships (full carrier, amphibious assault ship (LHA/LPH)) should be considered for such operations and their availability and emplacement for LHX deployment would be very tenuous due to probable higher priority assignments in times of full-scale alert.

c. (U) Recommended Approach. The option of adding external tank capacity (for the LHX-SCAT) and internal auxiliary tanks (for the LHX-Utility) is recommended for the following reasons:

(1) (U) Such hardware provisions are current technology.

(2) (U) There is only a slight weight penalty to be carried on non-deployment missions.

(3) (U) This option is independent of availability of other services (USN, USAF) assets and closely coordinated linkup requirements.

(4) (U) This option can readily be used for other extended-range missions, when desired.

d. (U) Self-Deployment Analysis. The self-deployment of LHX candidates using the recommended mode (auxiliary tanks) is outlined on the following pages. Deployment routes are shown in figure N-III-1 and correspond to LHX mission profiles 47 (northern route) and 48 (southern route). The aircraft performance data used for the analysis is shown in figure N-III-2. Many factors affect force buildup for the self-deployment mode, including weather, combat attrition rates, in-flight failures, range and speed of aircraft, crew rest periods, pre-positioning of flight crews and airport facilities; i.e., parking spaces, refuel rate, and crew quarters. The assumptions and limitations for this analysis are shown in figure N-III-3. Also, figures N-III-4 through N-III-7 provide comparative data among the LHX candidates in terms of number of aircraft arriving in theater within 7 days. It is obvious that the tilt rotor has a clear advantage due to its superior speed and range capability. However, by using pre-positioned crews, this advantage is significantly reduced over routes to Europe. Nevertheless, the tilt rotor alone has the 2,100-nm range capability and thus may reach Europe via either route with only one en route stop. Because of crew rest limitations, the tilt rotor made two en route stops via the northern route and three stops via the southern route.

Northern Route:

Station	Distance (nm)
Loring AFB (Maine)	Start
Goose Bay (Labrador)	477
Narssarssua (Greenland)	675
Keflavik (Iceland)	649
Prestwick (Scotland)	755
Mildenhall (England)	237
Heidelberg (West Germany)	390
Total	3,183

Southern Route:

Station	Distance (nm)
Pease AFB (New Hampshire)	Start
St. Johns (Newfoundland)	780
Flores (Azores)	1,055
Lajes (Azores)	197
Lisbon (Portugal)	835
Lyon (France)	822
Heidelberg (West Germany)	319
Total	4,008

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Figure N-III-1. (U) Self-deployment routes.

Aircraft	Range (nm)	Mission Gross Weight (pounds) (lb)	Payload (lb)	Block Speed (knots true airspeed)	Flight Time (hours) (hr)
Helicopter					
SCAT	740[a]	11,700	1,030	131	5.6
	1,240[b]	13,608	725	133	9.4
Utility	740[a]	11,511	2,000	131	5.6
	1,240[b]	13,422	296	129	9.6
Compound helicopter					
SCAT	740[a]	13,015	1,030	130	5.8
	1,240[b]	16,412	1,030	129	9.6
Utility	740[a]	13,407	1,530	130	5.8
	1,240[b]	16,800	1,100	129	9.6
Advancing blade concept (ABC)					
SCAT	740[a]	13,300	1,030	126	5.9
	1,240[b]	15,270	725	127	9.7
Utility	740[a]	13,215	2,000	126	5.9
	1,240[b]	15,113	296	127	9.7
Compound ABC					
SCAT	740[a]	14,315	1,030	129	5.7
	1,240[b]	16,414	296	131	9.4
Utility	740[a]	14,212	2,000	129	5.7
	1,240[b]	16,213	296	131	9.4
Tilt rotor					
SCAT	740[a]	12,135	1,030	217	3.4
	1,240[b]	13,927	1,030	217	5.7
	2,100[c]	15,124	350	215	9.9
Utility	740[a]	12,325	2,000	219	3.4
	1,240[b]	14,001	1,959	214	5.9
	2,100[c]	15,284	350	207	10.3

NOTES:

a. Longest leg of the northern route to Europe.

b. Longest leg of the southern route to Europe.

c. Longest leg of the Pacific route to Japan.

Figure N-III-2. (U) Aircraft performance, self-deployment.

-- The aircraft must have a fire-and-forget air-to-air weapon.

-- The aircraft must carry appropriate overwater survival equipment.

-- The aircraft must be equipped with range extension tanks as needed to meet the longest leg distance with a 10-knot headwind and a 10-percent fuel reserve.

-- Selected aircraft within the flight must be equipped with rescue hoists.

-- Selected aircraft must possess a long-range communication capability (high frequency (HF)/satellite communications).

-- Navigation systems must support long-range, overwater flight.

-- Selected aircraft must possess navigational radios capable of homing to survival radio beacons.

-- The attack helicopter battalion consists of 3 companies of 10 LHX-SCAT each and the headquarters and headquarters company.

-- Flight time must be limited to 8 hr per 24-hr period for a two-man crew (crew rest).

-- The use of pre-positioned crews requires a refuel rate of 75 aircraft per hr in order to maintain the 1-hr (maximum) ground time schedule.

-- Departure rate set at 180 aircraft (6 battalions) per day due to assumed airfield capacity for refuel, crew rest, and overnight parking. Company-sized flights (10 aircraft) depart at 5-minute intervals.

-- Weather delays, combat attrition, and in-flight failures were not simulated. Also, the logistics concerning backhaul of flight crews and auxiliary fuel tanks was not analyzed.

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Figure N-III-3. (U) Self-deployment assumptions and limitations.

Mode: Self-deploy

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Route: Northern to Europe

Unit: Attack helicopter battalion

Aircraft	Elapse Time (hr)	Flight Time (hr)	Overnight Stops	Number of Aircraft in Theater (7 days)
Helicopter	96.8	24.4	4	540
Helicopter compound	96.8	24.5	4	540
ABC	97.0	25.4	4	540
ABC compound	96.8	24.6	4	540
Tilt rotor	46.9	14.7	2	900

NOTES:

a. Crew rest provides for limiting flight time to 8 hr per 24-hr period.

b. Aircraft departures per day equal 180 (continental United States (CONUS)).

Figure N-III-4. (U) LHX deployability without pre-positioned crews.

Mode: Self-deploy

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Route: Northern to Europe

Unit: Attack helicopter battalion

Aircraft	Elapse Time (hr)	Flight Time (hr)	Overnight Stops	Number of Aircraft in Theater (7 days)
Helicopter	29.4	24.4	0	1,080
Helicopter compound	29.5	24.5	0	1,080
ABC	30.4	25.4	0	1,080
ABC compound	29.6	24.6	0	1,080
Tilt rotor	19.7	14.7	0	1,260

NOTES:

a. One hr for refuel and crew change at each stop.

b. Aircraft departures per day equal 180 (CONUS).

Figure N-III-5. (U) LHX deployability with pre-positioned crews.

Mode: Self-deploy

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Route: Southern to Europe

Unit: Attack helicopter battalion

Aircraft	Elapse Time (hr)	Flight Time (hr)	Overnight Stops	Number of Aircraft in Theater (7 days)
Helicopter	92.4	30.2	4	540
Helicopter compound	92.5	30.8	4	540
ABC	92.5	31.6	4	540
ABC compound	92.4	30.6	4	540
Tilt rotor	73.3	18.5	3	720

NOTES:

a. Crew rest provides for limiting flight time to 8 hr per 24-hr period.

b. Aircraft departures per day equal 180 (CONUS).

Figure N-III-6. (U) LHX deployability without pre-positioned crews.

Mode: Self-deploy

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Route: Southern to Europe

Unit: Attack helicopter battalion

Aircraft	Elapse Time (hr)	Flight Time (hr)	Overnight Stops	Number of Aircraft in Theater (7 days)
Helicopter	35.1	30.2	0	1,080
Helicopter compound	35.8	30.8	0	1,080
ABC	36.6	31.6	0	1,080
ABC compound	35.6	30.6	0	1,080
Tilt rotor	23.5	18.5	0	1,140

NOTES:

a. One hr for refuel and crew change at each stop.

b. Aircraft departures per day equal 180 (CONUS).

Figure N-III-7. (U) LHX deployability with pre-positioned crews.

N-III-3. (U) AIR TRANSPORTABILITY. The pertinent issues concerning air transportability are designing the LHX (SCAT and Utility) so that all subsystem components function properly and still meet the air transport load/off-load times and designing the LHX-SCAT (and Utility variance) configurations low enough to clear the C-141 ceiling height and still retain the crash force absorption in the landing gear struts. For the LHX-SCAT, the 30mm cannon must be located near the nose for adequate up/down swiveling. The pilot's night vision system must be located above the weapon, and the EOTADS must be located away from the gun flash. The millimeter wave (MMW) radar antenna must be top side-mounted for full effectiveness. All this, coupled with sufficient rotor-to-fuselage clearance (for the helicopter configuration), forces LHX height growth into the 103 inches of usable height of the C-141 aircraft. The floor depth and fuselage-to-ground clearance can be minimized only at a serious cost to crashworthiness. This creates the necessity to use landing gear kneeling to permit ramp crest clearance over the 15-degree floor-to-ramp hinge point in the C-141 (see figure N-III-8).

	C-130H	C-141B	C-17	C-5A
Cargo compartment (usable)				
Main floor length (inches)	481	1,114	1,056	1,459
Main floor width (inches)	111	111	216	216
Ceiling height (inches)	104	103	148	108
				156
Number of LHX-SCAT helicopters	2	4	6-8	10-12

NOTES:

a. MIL-A-8421F requires a minimum of 6 inches clearance between payload and aircraft, except the floor, during loading and flight (applicable to all models).

b. C-5A has "lip-roof" compartment, width is 228 inches to height of 114 inches, tapering to 156 inches width at 162 inches height.

c. C-17, initial operational capability scheduled for fiscal year 92.

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Figure N-III-8. (U) USAF transport aircraft characteristics.

a. (U) One method of reducing the LHX height for transportability is to retract the rotor and hub into the pylon cowling after the blades have been folded. This can be implemented using a mast up-lock and a hand crank-powered rack and pinion arrangement (vertically) on the main rotor mast. While this method has never been used, the idea appears to be technically feasible at a relatively low weight and cost penalty.

b. (U) The LHX fuselage-to-ground clearance can be adjusted (from normal operating height) by strut length adjustment. This is currently done on the UH-60A and AH-64A. Both the aircraft use an electrically powered hydraulic pressure generator, a method adaptable to the LHX.

c. (U) While complex and costly, the LHX rotor system, blades, and/or tail section could be designed for sequenced, automatic folding and/or unfolding given a source of hydraulic and/or electrical power (ground cart or auxiliary power unit (APU).

d. (U) To design the LHX-SCAT so as to require no change (with the exception of the lifting/propulsion rotors) to be inserted into a C-141B is impossible regardless of the configuration (helicopter, tilt rotor, ABC, etc.). Adoption of this approach would preclude space for any mission equipment and, in the LHX-Utility, would not permit adequate cabin space for passengers or cargo. The prime reasons are as follows:

(1) (U) The VTOL lift system must be sufficiently high above the fuselage and engine inlets to preclude performance problems.

(2) (U) The weapon systems must be located so that antennas and sensors work properly and the guns/munitions do not affect the sensors or potentially damage the airframe.

(3) (U) There must be adequate fuselage space for all fuel cells, avionics equipment, munitions, and storage.

(4) (U) There must be, within the fuselage and landing gear design, adequate crashworthiness.

e. (U) The automatically powered component folding option is possible if there is a willingness to pay the weight (and performance), cost, and reliability/maintainability penalties. Such features as automatic rotor blade folding, tail folding, landing gear kneeling, etc., have been incorporated into past and current fleet helicopters primarily for USN shipboard operations. In those cases, extensive hydraulic and electrical sequencing is required. However, such systems permit quite rapid preparation for movement between the flight deck and the hangar deck.

f. (U) It should be noted that designing a tail pylon folding point into a composite fuselage creates significant structural problems due to disruption of the high-strength longitudinal load-carrying fibers, the need for high-strength hinge/latch points, and the need for a tail drive shaft automated disconnect device for the helicopter configuration. For these reasons, it is

felt that a tail pylon folding point (manual or automatic) cannot be justified on the LHX baseline configuration. As for the LHX tilt rotor baseline, the wing has been pylon-mounted above the fuselage to facilitate swiveling the wing longitudinally over the fuselage for air transport. The option to design hinge points for tilt rotor wing folding must be rejected due to wing strength and stiffness requirements between the rotors and because it would create a requirement for interrotor drive shaft quick-disconnect couplings. The swiveling wing concept for the LHX is a manually operated version of the powered swiveling wing concept chosen for the USN JVX aircraft.

g. (U) In order to make realistic assessments of the LHX configurations for air (and ship) transportability, it is necessary to review the results of current fleet aircraft loading/off-loading trials. Close attention was given to data from the UH-60A and the AH-64A loading trials since those aircraft had air transportability requirements in their design specifications (see figure N-III-9).

Aircraft Model	Maximum Aircraft per C-141	Load and Secure		Off-Load Prepare to Fly		Number in Load Crew
		MN-HR	EL-HR	MN-HR	EL-HR	
UH-60A	2	22.0	2.6	22.0	2.6	6
AH-64A	2	17.4	2.4	18.1	2.7	7
UH-1H	3 (4)	30.0	5.0	40.0	7.0	7
AH-1S	3 (4)	24.0	4.0	36.0	6.0	6
OH-58	4 (8)	7.5	1.5	10.0	3.0	5
OH-6A	6	6.0	3.0	6.0	3.0	4

NOTE: Load and off-load include disassembly/assembly time per transported aircraft; further levels of teardown, in parentheses, required longer times per aircraft.

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Figure N-III-9. (U) Current fleet air transport in C-141B aircraft.

h. (U) It can be seen that the loading/off-loading times, load crew size, and ground equipment required are general functions of helicopter size and complexity. An exception to this is the AH-64A Apache, which was designed to transport requirements, although extensive ground support equipment (GSE) is required. The LHX overall physical design parameters (weight, length, width, etc.) are roughly equivalent to the UH-1 and AH-1 family of helicopters. Although extensive air transport load/off-load time (and GSE) improvements can be expected over those aircraft by initial "hard-line" specifications for air transportability, the LHX MEP weapons and navigational sensors

create problems which can complicate a "neat" package for rapid ingress/egress and C-141B cargo compartment storage.

i. (U) Each of the LHX baseline configurations are discussed for air transportability by the C-141B aircraft in the following paragraphs. In performing air transport loading/off-loading layouts and considering all subsystem component location requirements, it rapidly becomes apparent that the MMW radar antenna on top of the mast/fuselage creates an excessive height requirement for air transport. This also applies to the LHX-Utility varieties which also have this antenna. Additionally, the LHX tilt rotor SCAT has the HELLFIRE missile exposed below the underside of the fuselage. As missiles are fired, additional ones are lowered into the firing position. Consequently, to permit C-141 (or C-5A) ramp crest clearance, the lower launch tube fairing must be removed for air transport. This problem is precluded on the LHX-SCAT helicopter by "side-saddle" mounting the missiles and incorporating a launch tube lateral extender mechanism to move the rocket flash away from the cockpit canopy. Another characteristic designed into all the LHX baselines for air transport is a kneelable main landing gear. This is necessary to obtain overhead clearance in the C-141B and provide an adjustable belly-to-ramp crest clearance for ingress/egress.

(1) (U) SCAT helicopter. The SCAT helicopter configuration incorporates manually folded main rotor blades, kneeling main landing gear, and a unique, built-in, manually powered mechanism to lower the main rotor mast to obtain ceiling clearance in the C-141. Three SCAT helicopters can be transported in the C-141B with minimal disassembly; with additional removal of only the HF antenna, four LHX-SCAT helicopters can be transported in a C-141B. The baseline aircraft, by using main landing gear kneeling and/or extension, does not need auxiliary ramp buildup as do virtually all current fleet aircraft. The analysis shows that each SCAT helicopter can be prepared and loaded by five men in 1.12 hr and/or off-loaded and prepared for flight in the same time. The use of automatically powered main rotor blade indexing and folding could reduce this time to 0.48 hr.

(2) (U) Utility helicopter. The utility helicopter variant, as well as the SCAT helicopter, incorporates the same manually folded main rotor blades, the kneeling/extendable main landing gear, and the crank-down main rotor mast. Four utility helicopters can be transported in the C-141B with minimum disassembly. For utility helicopter loading, the infrared (IR) jammer does not have to be removed, but the HF antenna does have to be removed. Auxiliary ramps do not have to be built due to the main landing gear kneeling/extension provision. Five men can prepare and load one utility helicopter in 0.95 hr (57 minutes) and/or off-load and prepare the aircraft for flight in the same time. As with the SCAT, the use of automatic blade folding could reduce this time by approximately one-half.

(3) (U) SCAT tilt rotor. The SCAT tilt rotor will use the same folding procedure for air transport as developed for the USN/US Marine Corps JVX for shipboard operations. For the LHX baseline, however, the main rotor blades (two out of three on each rotor) will be manually removed (versus automatically folded for the JVX), and the wing will be manually swiveled over

the fuselage (versus powered on the JVX). Also, the missile stowage becomes internal on a vertical rack. The ready-to-fire missiles extend out the bottom of the fuselage. This bottom row of missiles and surrounding drag-reduction fairing must be removed to permit ingress/egress from the C-141 transport. The main rotor blades will weigh about 81 lb each and can thus be handled by two men. The engine IR suppressors must be removed, but these only weigh 33 lb each and can be manually removed. Since only the bottom row of missiles is affected, boresighting upon reinstallation is not an anticipated requirement. The MMW radar antenna is mounted on top of the vertical stabilizer with an anticipated weight of about 85 lb and can be removed by two men. The outer portion of each horizontal stabilizer is hinged and can be manually folded up and pinned by one man. The aircraft APU will have to be operated during preparation for loading (and preparation for flight) to provide subsystem power to rotate the main rotor pylons to the horizontal (forward flight) position after the main rotor blades have been removed. A maximum of two SCAT tilt rotor aircraft can be transported in the C-141B with the minimum disassembly. Note that auxiliary ramps are not required to be built. Seven men can prepare and load one SCAT tilt rotor in 0.83 hr (50 minutes) and/or off-load and prepare the aircraft for flight in the same time. The use of LHX-type automated folding and wing swiveling could reduce this time to 0.58 hr (35 minutes).

(4) (U) Utility tilt rotor. The utility tilt rotor load/off-load procedure is identical to the SCAT tilt rotor LHX, except there are no missile pods or fairings to remove/reinstall--hence, shorter preparation time. A maximum of two utility tilt rotor aircraft can be transported in the C-141B with minimum disassembly. Seven men can prepare and load one aircraft in 0.72 hr (43 minutes) and offload and prepare the aircraft in the same amount of time.

(5) (U) SCAT ABC. The ABC has a unique problem for air transport due to its inherent dual rotor height above the fuselage. This creates a choice of completely removing the main rotor shafts and hubs or folding the main gearbox and rotor hubs down. Either way precludes the use of blade folding (manual or automatic). Consequently, all six main rotor blades must be removed. Also, folding the main gearbox and rotor hubs is considered to be less time-consuming than removal; therefore, it is the preferred method. Four aircraft may be loaded/unloaded by four men within 1.22 hr (73 minutes) per aircraft, including preparation time.

(6) (U) ABC utility. The ABC utility aircraft incorporates the same manually folded main gearbox and rotor head concept as the SCAT ABC. Also, the number of aircraft transported, loading/off-loading times, and manpower required are determined to be essentially the same as for the SCAT version.

(7) (U) ABC compound SCAT. This aircraft is almost identical to the baseline ABC SCAT with the addition of short wings to support the missile pods and a pusher propeller. For air transport, two aircraft can be loaded with minimal disassembly by four men in 1.22 hr (73 minutes) per aircraft.

(8) (U) ABC compound utility. The times and tasks are identical to the ABC utility variant. Two aircraft can be carried in the C-141B; the aircraft can be loaded or unloaded in 1.22 hr (73 minutes) per aircraft by four men.

(9) (U) Helicopter compound SCAT. This aircraft will have the same air transport features as used in the baseline SCAT helicopter. Additionally, it will have to incorporate outer wing removal joints; the pusher propeller blades can be indexed to provide height clearance for the C-141B cargo bay. Two compound helicopter SCAT aircraft can be transported with minimal disassembly. Five men can prepare and load one aircraft in 0.95 hr (57 minutes) and off-load and prepare the aircraft in the same amount of time.

(10) (U) Helicopter compound utility. This configuration is identical to the SCAT except that the stub wings can be folded down to stay within the C-141B width limits. Two compound helicopter utility aircraft can be transported in the C-141B with minimal disassembly. Only four men are needed to prepare and load one aircraft in the same time as for the SCAT version (0.95 hr). The use of automatic blade folding could reduce this time to 0.65 hr.

j. (U) The number of aircraft per transporter, loading and unloading times, ground crew size, and amount of GSE required are reflected in figure N-III-10. It should be noted that all LHX configurations may be loaded or offloaded within 15 minutes, excluding preparation time. Of the operational factors mentioned above, the number of aircraft per air transporter is the key factor for force buildup in theater.

Aircraft	Number Transported	Load/Off-Load Time (hr)*	Number of Personnel in Ground Crew	Number of GSE Items
Helicopter				
SCAT	4	1.37	5	9
Utility	4	0.95	5	9
Helicopter compound				
SCAT	2	0.95	5	10
Utility	2	1.20	4	9
ABC				
SCAT	4	1.23	4	10
Utility	4	1.22	4	12
ABC compound				
SCAT	2	1.22	4	10
Utility	2	1.22	4	12
Tilt rotor				
SCAT	2	0.83	7	10
Utility	2	0.72	7	9

*Includes preparation.

NOTE: All configurations can be loaded/off-loaded in 15 minutes.

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Figure N-III-10. (U) Air transport (C-141B).

N-III-4. (U) LHX SHIPBOARD COMPATIBILITY.

a. (U) Shipboard compatibility for aircraft encompasses a number of considerations.

(1) (U) This would include operating size; i.e., clearance from ship superstructures and deck spotting plans and stowage size (how many aircraft are stowed, including the ability to convert from the stowage mode to the operating mode with relative ease and in a short period of time). Clearance for the underside of the aircraft when passing over a hangar doorsill is also a factor.

(2) (U) Ability to operate off decks during high wind conditions, periods of darkness, and marginal weather.

(3) (U) Resistance to the corrosive effects of salt spray and stack gases from the ship, to include a capability for fresh water washdown for the engine as well as the airframe.

(4) (U) Shielding from the powerful communication, navigation, and electronic warfare emitters aboard ship.

b. (U) Shipboard operations were not discussed in the Trade-Off Determination document; therefore, a TOA cannot be performed. Additional information and analyses are recommended.

N-III-5. (U) FINDINGS.

a. (U) Self-Deployment.

(1) (U) In the self-deployment mode, the tilt rotor is the preferred system due to its superior range and speed which allows route flexibility, reduction of en route refuel stops, and improved ferry mission time.

(2) (U) All LHX candidates meet the desired 1,240-nm ferry range, thereby allowing route flexibility (both northern and southern routes to Europe) which would result in avoidance of en route adverse weather or possible threat forces.

(3) (U) The preferred self-deployment mode is the use of auxiliary tanks as opposed to air-to-air refueling, in-flight towing, integral fuel tank capacity, or ship hopping.

(4) (U) Over an extended period, the speed and range advantage of the tilt rotor is significantly reduced since the departure rate of aircraft becomes the dominant factor for force buildup.

(5) (U) Many factors affect force buildup (arrival rate) in theater; i.e., weather, combat attrition, in-flight failures, range and speed of aircraft, crew rest periods, pre-positioning of flight crews, and airport facilities (aircraft parking spaces, refueling rates, and crew quarters).

b. (U) Air Transport.

(1) (U) The helicopter and the ABC aircraft are the preferred systems because twice as many may be loaded (in the C-141B) as other candidates and with reasonable preparation times as well.

(2) (U) Although the number of aircraft which may be transported by the C-141B carrier is important, other factors such as load/unload time, ground crew size, and the amount of GSE are of equal importance.

(3) (U) The greater range and speed advantage of the air transporter over the self-deployment mode significantly improves route flexibility and response time. Recycling assets (C-141B) by using backhaul missions will greatly reduce the number of air transporters required for airlift operations. However, the air transport mode complements the self-deployment capability but does not replace it.

c. (U) Shipboard Operations and Transportability. The level of LHX marinization required for shipboard operations and transportability has not been adequately defined to date. Therefore, specific trade-offs affecting weight, costs, and technical risks are not known.

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ANNEX IV TO APPENDIX N

VERTICAL FLIGHT (VF) ANALYSIS

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ANNEX IV TO APPENDIX N
VERTICAL FLIGHT (VF) ANALYSIS

N-IV-1. PURPOSE. The vertical flight (VF) analysis is intended to present the costs in weight and dollars to achieve increased performance at altitudes above 4,000 feet (ft) pressure altitude. The trade-off determination (TOD) has developed baseline designs from which the delta weight and costs are discussed. The baseline designs include a derivative (A129 and S75), helicopter, compound helicopter, advancing blade concept (ABC), compound ABC, and a tilt rotor (TR). The Scout-Attack (SCAT) baselines were designed (modified for derivatives) to meet a vertical rate of climb (VROC) of at least 500 feet per minute (fpm) at 4,000 ft/95° Fahrenheit (F) at .95 intermediate rate power (IRP). The Utility designs were specified to meet a hover out-of-ground effect (HOGE) level at this same altitude, temperature, and power condition. In addition, the SCAT designs had to meet the requirements of the security mission specified for the Middle East (mission 16), and the Utility designs had to meet the requirements of the special operations forces (SOF) insertion mission in the Middle East (mission 35). The SCAT payload was specified as 1,030 pounds (lb) while the Utility payload was set at 1,530 lb. The designs which evolved from the TOD effort are presented in figure N-IV-1.

N-IV-2. BACKGROUND. The Army is continuously concerned about VF capability in a "high," "hot" condition. During the Utility Tactical Transport Aircraft System (UTTAS) development process, an extensive analysis was conducted to establish the altitude and temperature criteria to which Army rotorcraft should be designed. This analysis is included herein for the reader's information.

N-IV-3. LIMITATIONS. This analysis will address those Light Helicopter Family (LHX) candidates provided by the TOD.

N-IV-4. METHODOLOGY. The methodology developed for this subanalysis is three-part in form. The first part centers on the baseline TOD designs and looks at the overall VF capability at other altitudes. Part two considers the ramifications of designing the LHX to an altitude above 4,000 ft and alternate IRP level. Part three discusses the "what ifs" given a fixed engine size. In each part, the effect on weight and cost is presented.

N-IV-5. RESULTS/ANALYSIS.

a. Baseline Designs Review.

(1) Figure N-IV-2 presents the maximum gross weight achievable for the requirement of maintaining a 500-fpm VROC at 0 forward velocity at 95 percent IRP and 4,000 ft/95°F. As shown, the ordering of designs is the compound ABC, TR, compound helicopter, ABC, helicopter, and A129. Except for the A129, all baselines at the design altitude have a mission payload of 1,030 lb; the A129 has a payload of approximately 920 lb. Moving off the design altitude changes the payload as shown in figure N-IV-3. Inspection of

	4,000 ft/95°F		95% IRP	
Design	Type	Design Gross Weight (lb)	VROC (fpm)	Payload (lb)
Derivative				
A129	SCAT	8,884	500	891
S75	Utility	10,930	0	1,440
Helicopter	SCAT	9,096	715	1,030
	Utility	9,747	0	1,530
Compound Helicopter	SCAT	10,441	773	1,030
	Utility	10,962	0	1,530
ABC	SCAT	10,292	713	1,030
	Utility	10,954	0	1,530
Compound ABC	SCAT	11,182	795	1,030
	Utility	11,838	0	1,530
TR	SCAT	10,850	653	1,030
	Utility	11,371	0	1,530

Figure N-IV-1. Baseline designs.

LHX SCAT BASELINE DESIGNS

VROC= 500 FPM AT 95% IRP   TEMP= 95° F

ALTITUDE VS GROSS WEIGHT

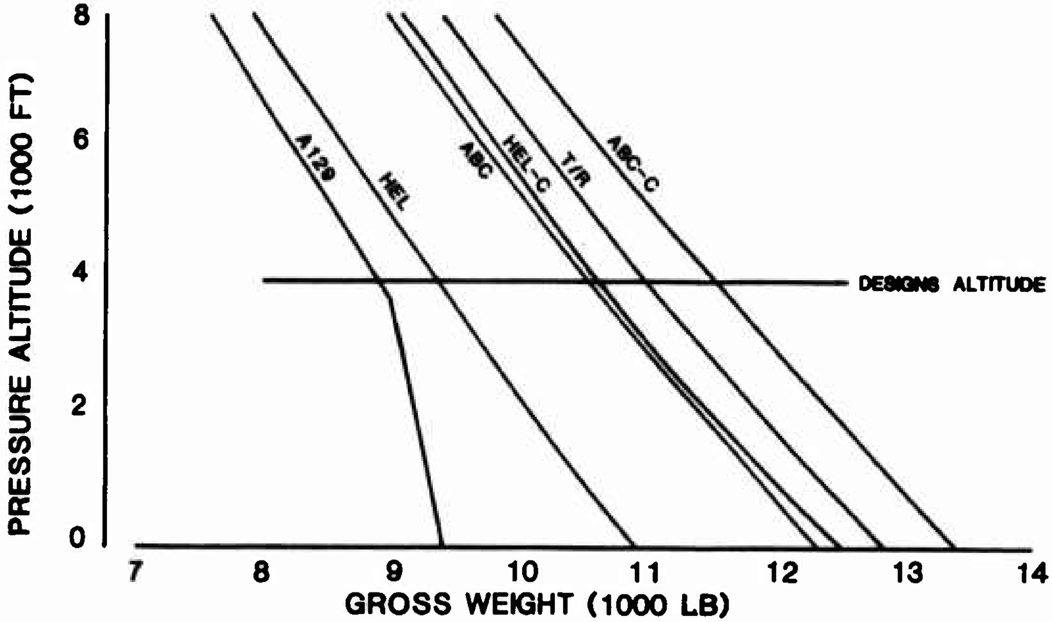

Figure N-IV-2. SCAT, altitude versus gross weight, 500 fpm VROC, 4,000 ft, 95°F.

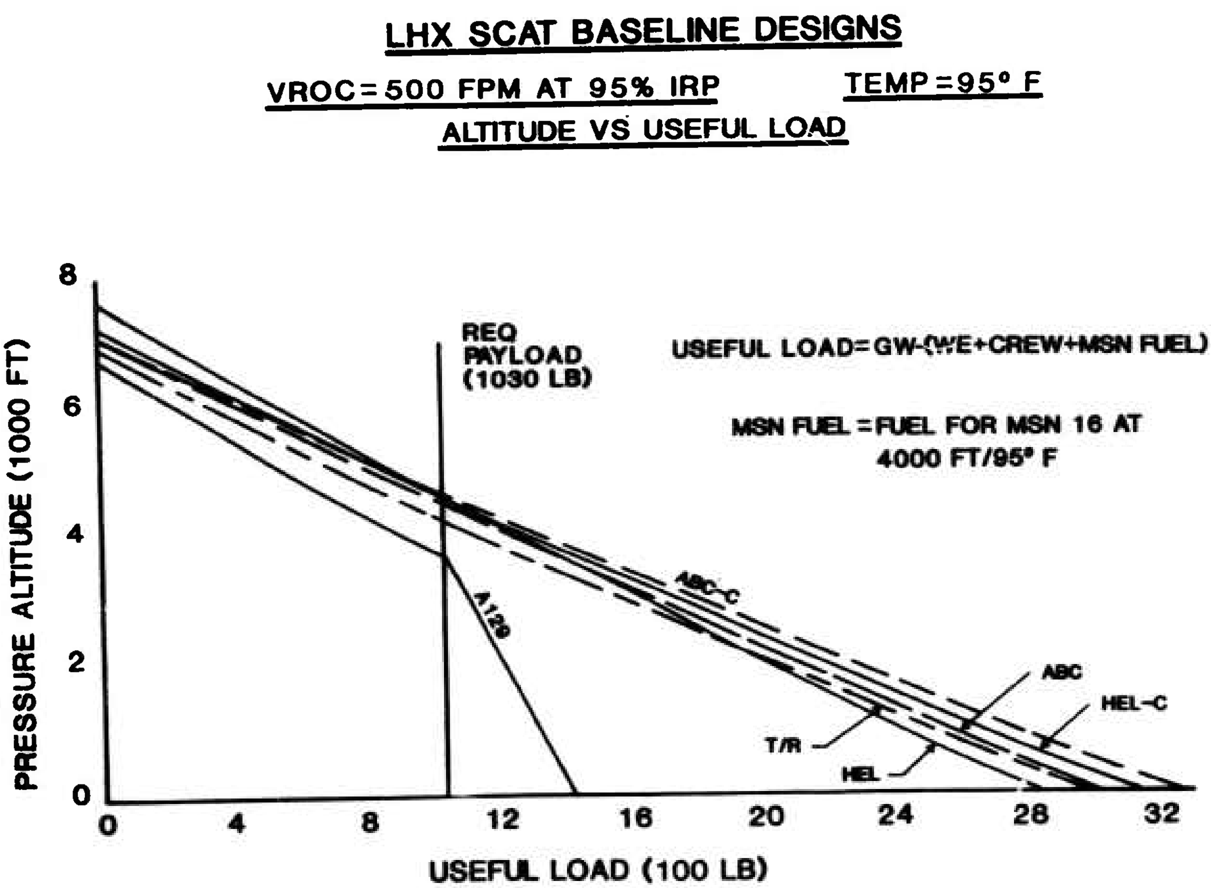

Figure N-IV-3. SCAT, altitude versus useful load, 500 fpm VROC, 4,000 ft, 95°F.

figure N-IV-3 and review of figure N-IV-2 points out that the apparent 2,500-lb advantage of the compound ABC over the helicopter at sea level is, in fact, only a payload advantage of 414 lb. The advantage is eroded away by an increased empty weight plus increased mission fuel requirements of the compound ABC. This same interrelationship explains the reasons for the useful load data presented in figure N-IV-3.

(2) From figure N-IV-3, it can be seen that each new design baseline can maintain the required payload to a slightly higher altitude (except the A129) than 4,000 ft. For the higher altitudes, the payload of each design drops off to the extent that with an increase of 1,000 ft in altitude, the payload loss is over 300 lb or, alternatively, three HELLFIRE missiles. The rate of payload drop for each rotorcraft is:

-- A129 - 329 lb/1,000 ft.

-- Helicopter - 349 lb/1,000 ft.

-- TR - 385 lb/1,000 ft.

-- Compound helicopter - 396 lb/1,000 ft.

-- ABC - 420 lb/1,000 ft.

-- Compound ABC - 448 lb/1,000 ft.

Although the A129 is most efficient, it begins at a deficit, i.e., 920 lb payload at 4,000 ft. Therefore, the more efficient rotorcraft is the helicopter with the compound ABC being the worst; the exact opposite situation one could have arrived at by only looking at figure N-IV-2. The significant point to be realized is that given the requirement to operate at increased altitude, mission effectiveness is deteriorated to the point that all decisions are unacceptable.

b. Design Variations.

(1) The LHX Trade-off Analysis (TOA) considered the option of increasing the altitude design conditions beyond 4,000 ft in order to improve operational capability for Middle East operations. The need for a capability at increased altitudes has been investigated for both the UH-60 (UTTAS study conducted between 1965 and 1968) and reverified for the 1979 Advanced Scout Helicopter (ASH) study effort. The need for increased operational capability remains valid for the present design considerations. The arguments developed to support the need are contained in appendix O of the UTTAS report. The findings of these studies are summarized below:

-- A design standard of 6,000 ft/95°F with appropriate allowances for flight maneuvers and mechanical deterioration is (actually) needed to operate effectively in much of the Middle East.

-- A design standard of 2,000 ft/95°F plus allowances is probably adequate for Central Europe.

-- A design standard of 4,000 ft/95°F plus allowances is the minimum acceptable level for worldwide operations when compromise is necessitated by the availability of suitable engines and/or airframes.

-- Design points for new development helicopters between 6,000 ft/95°F and 4,000 ft/95°F are cost effective in terms of worldwide operational gains relative to cost.

The following analysis looks at the opportunity to achieve increased capability. Options at 6,000 ft and 8,000 ft were investigated and the results are reported in the following paragraphs:

(2) Design variations to increase mission performance at altitude which were investigated are presented in figure N-IV-4.

(3) The first case presented in figure N-IV-4 is for the condition where the SCAT meets the basic VROC requirement of 500 fpm at .95 IRP. As a result, the corresponding Utility which must have a HOGE cannot carry the full payload of 1,530 lb. This approach results in a SCAT that is designed for 4,000 ft and is also capable of performing at 6,000 ft with a vertical flight capability of HOGE. However, the Utility design payload capability would deteriorate to the extent that it could only carry two troops. When the design altitude is increased to 6,000 ft, the Utility is still unable to carry the full payload although the margin has decreased. The Utility would be capable of carrying five troops. It should be noted that all references to number of troops is in addition to the two Stingers. Obviously, the Utility design at 6,000 ft would be more than capable of carrying the full payload given that operations are conducted at 4,000 ft. Similarly, a SCAT designed to 8,000 ft with a fallout Utility results in a Utility with a lift capability of five troops at 8,000 ft, but six troops at 6,000 ft. The percent changes for case 1 are presented in figure N-IV-5.

(4) Case 2 represents an approach to increase the altitude capability and at the same time provide a power margin for future use to offset weight growths that historically have degraded the desired flight characteristics of the system at a very early age, some even before the initial operational capability (IOC). Once again, the Utility payload is a fallout which turns out to be similar to case 1. The end result is that the payloads are similar but increase in weight and cost are higher by 2 to 6 percent in weight and 2 to 4 percent in dollars. These results are presented in figure N-IV-6. The designs at 8,000 ft would provide the desired results at 6,000 ft. The changes in weight and dollars from .95 IRP to .90 IRP at 4,000 ft are presented in figure N-IV-7.

Case	Percent IRP	Ambient (1,000 ft)	Ambient (°F)	VROC (fpm) SCAT	VROC (fpm) Utility	Payload (lb) SCAT	Payload (lb) Utility
1	.95	4	95	500	0	1,030	Fallout
	.95	6	95	500	0	1,030	Fallout
	.95	8	95	500	0	1,030	Fallout
2	.90	4	95	500	0	1,030	Fallout
	.90	6	95	500	0	1,030	Fallout
	.90	8	95	500	0	1,030	Fallout
3(1)	.95	4	95	$\geq$500	0	1,030	1,530
	.95	6	95	$\geq$500	0	1,030	1,530
	.95	8	95	$\geq$500	0	1,030	1,530
4	.90	4	95	$\geq$500	0	1,030	1,530
	.90	6	95	$\geq$500	0	1,030	1,530
	.90	8	95	$\geq$500	0	1,030	1,530
5(2)	.95/.90	5	95	$\geq$500	0	1,030	Fallout

NOTES:

1. Design criteria for baseline.
2. Data presented is interpolated between 4,000 and 6,000 ft.
3. Mission equipment package (MEP): SCAT = 1,288 lb; Utility = 945 lb.

Figure N-IV-4. Design variations.

.95 IRP Designs   VROC: SCAT = 500 fpm, Utility = HOGE   Payload: SCAT = 1,030 lb, Utility = Fallout

Design	4,000-6,000 ft					4,000-8,000 ft					
	SCAT		Utility			SCAT		Utility			
	%GW	%$	%GW	%$	P/L	%GW	%$	%GW	%$	Payload 6K	Payload 8K
HEL*	4.38	2.68	1.58	3.12	5 Trp	11.24	6.92	7.95	9.14	6 Trp	5 Trp
HEL-C*	4.21	2.63	1.85	3.11	5 Trp	12.62	8.13	9.65	9.63	6 Trp	5 Trp
ABC	3.40	2.23	.87	2.48	5 Trp	13.22	9.05	9.93	11.98	6 Trp	5 Trp
ABC-C*	3.97	2.34	1.66	4.14	5 Trp	14.32	11.39	12.83	14.61	6 Trp	5 Trp
TR	4.88	3.43	3.85	4.05	5 Trp	12.95	8.95	13.44	13.60	5 Trp	4 Trp

NOTES:

1. Changes are relative to baseline designs.

2. The change in cost is based on the average flyaway cost for 1,000 units.

*HEL - helicopter
HEL-C - compound helicopter
ABC-C - compound ABC

Figure N-IV-5. SCAT design change impact.

.90 IRP Designs	VROC: SCAT = 500 fpm Utility = HOGE					Payload: SCAT = 1,030 lb Utility = Fallout				
	4,000-6,000 ft					4,000-8,000 ft				
	SCAT		Utility			SCAT		Utility		
Design	%GW	%$	%GW	%$	Payload	%GW	%$	%GW	%$	Payload
HEL	6.32	3.99	3.47	4.71	5 Trp	13.63	8.57	10.35	10.17	5 Trp
HEL-C	6.60	4.36	4.33	5.18	5 Trp	16.18	10.65	12.77	12.61	5 Trp
ABC	5.80	3.90	3.30	4.48	5 Trp	16.28	12.38	12.83	14.45	5 Trp
ABC-C	10.17	8.41	8.67	10.89	5 Trp	17.83	13.99	16.43	17.87	5 Trp
TR	7.20	5.18	5.96	6.10	5 Trp	16.42	11.55	13.44	13.60	4 Trp

NOTES:

1. The change in cost is based on the average flyaway cost for 1,000 units.

2. Changes are relative to baseline designs.

Figure N-IV-6. SCAT design change impact.

VROC: SCAT = 500 fpm Utility = HOGE			Payload: SCAT = 1,030 lb Utility = 1,530 lb		
	.95 IRP to .90 IRP at 4,000 Ft				
	SCAT		Utility		
Design	% GW	% $	% GW	% $	Payload
HEL	1.57	.99	1.39	1.13	6 Trp
HEL-C	2.13	1.40	2.11	1.83	6 Trp
ABC	2.15	2.75	2.11	1.78	6 Trp
ABC-C	2.26	1.90	2.16	2.13	6 Trp
TR	1.24	.86	.15	.14	6 Trp

Figure N-IV-7. SCAT design change impact.

(5) Case 3 was designed to investigate the relative changes in weight and cost associated with changing the design point from 4,000 ft/95°F/.95 IRP to 6,000 ft and 8,000 ft at the same temperature and power setting and with the additional stipulation that the Utility meet the desired payload. The cost for case 3 is approximately .50-4.00 percent in weight and .25-4.00 percent in dollars higher than case 1. The changes in weight and cost relative to designs at 4,000 ft are presented in figure N-IV-8. The information for 8,000 ft was not developed because it appeared to be more than adequate, i.e., overdesign considering what the 8,000 ft designs for a 500 fpm SCAT with Utility fallout indicated.

(6) Case 4 investigated the impact on design gross weight and cost that resulted by changing the design power level to .90 IRP. As in case 3, the stipulation was that the Utility meet the desired payload. The changes in weight and cost relative to designs at 4,000 ft are presented in figure N-IV-9. Information for 8,000 ft was not developed because of the reasons noted for case 3.

.95 IRP Designs VROC: SCAT = 500 fpm, Utility = HOGE Payload: SCAT = 1,030 lb, Utility = 1,530 lb

	4,000-6,000 Ft				
	SCAT		Utility		
Design	% GW	% $	% GW	% $	Payload
HEL	5.53	3.46	5.21	4.23	6 Trp
HEL-C	6.15	4.04	5.57	4.78	6 Trp
ABC	4.78	4.60	4.67	4.36	6 Trp
ABC-C	5.44	4.55	5.22	5.17	6 Trp
TR	5.29	3.68	4.77	4.67	6 Trp

NOTES:

1. The change in cost is based on the average flyaway cost for 1,000 units.

2. Changes are relative to baseline design.

Figure N-IV-8. SCAT design change impact.

.90 IRP Designs	VROC: SCAT = 500 fpm Utility = HOGE		Payload: SCAT = 1,030 lb Utility = 1,530 lb		
	4,000-6,000 Ft				
	SCAT		Utility		
Design	% GW	% $	% GW	% $	Payload
HEL	7.62	4.77	7.26	5.92	6 Trp
HEL-C	8.76	5.75	8.15	6.98	6 Trp
ABC	7.49	6.56	7.35	7.04	6 Trp
ABC-C	8.32	6.98	8.03	7.95	6 Trp
TR	6.96	5.20	7.85	7.70	6 Trp

NOTES:

1. The change in cost is based on the average flyaway cost for 1,000 units.

2. Changes are relative to baseline designs, i.e., .95 IRP/4,000 ft.

Figure N-IV-9. SCAT design change impact.

(7) Case 5 looked at the aspect of designing the rotorcraft at 5,000 ft for both power levels and then investigating the performance (payload/VROC) characteristics at 6,000 ft. The designs developed at .95 IRP were evaluated to determine the performance at 6,000 ft based on operating at .95 IRP; however, the .90 IRP designs were evaluated on the basis of operating at 6,000 ft at .95 IRP. For both power design levels, the data for 5,000 ft designs is an interpolation of the data at 4,000 ft and 6,000 ft. Graphical representations of this analysis are presented in figures N-IV-10 through N-IV-19. Inspection of the data reveals the expected, i.e., the .90 IRP designs give increased capability at 6,000 ft when operated at .95 IRP versus the .95 IRP designs operated at 6,000 ft. Figure N-IV-20 presents a summary of estimated capabilities of the 5,000 ft designs operated at 6,000 ft. The number of troops is based on a 1-pound per 1 fpm VROC trade-off, e.g., the helicopter Utility at .90 IRP, operated at 6,000 ft would have a negative VROC of -200 fpm; however, by offloading one troop, it would then have a HOGE capability. From figure N-IV-20, it appears that the helicopter/compound helicopter provide the better capability while the TR is the least desirable. The fall off in TR vertical capability was shown in paragraph (2), figure N-IV-3. Comparing the increased weight and cost of the estimated 5,000 ft designs

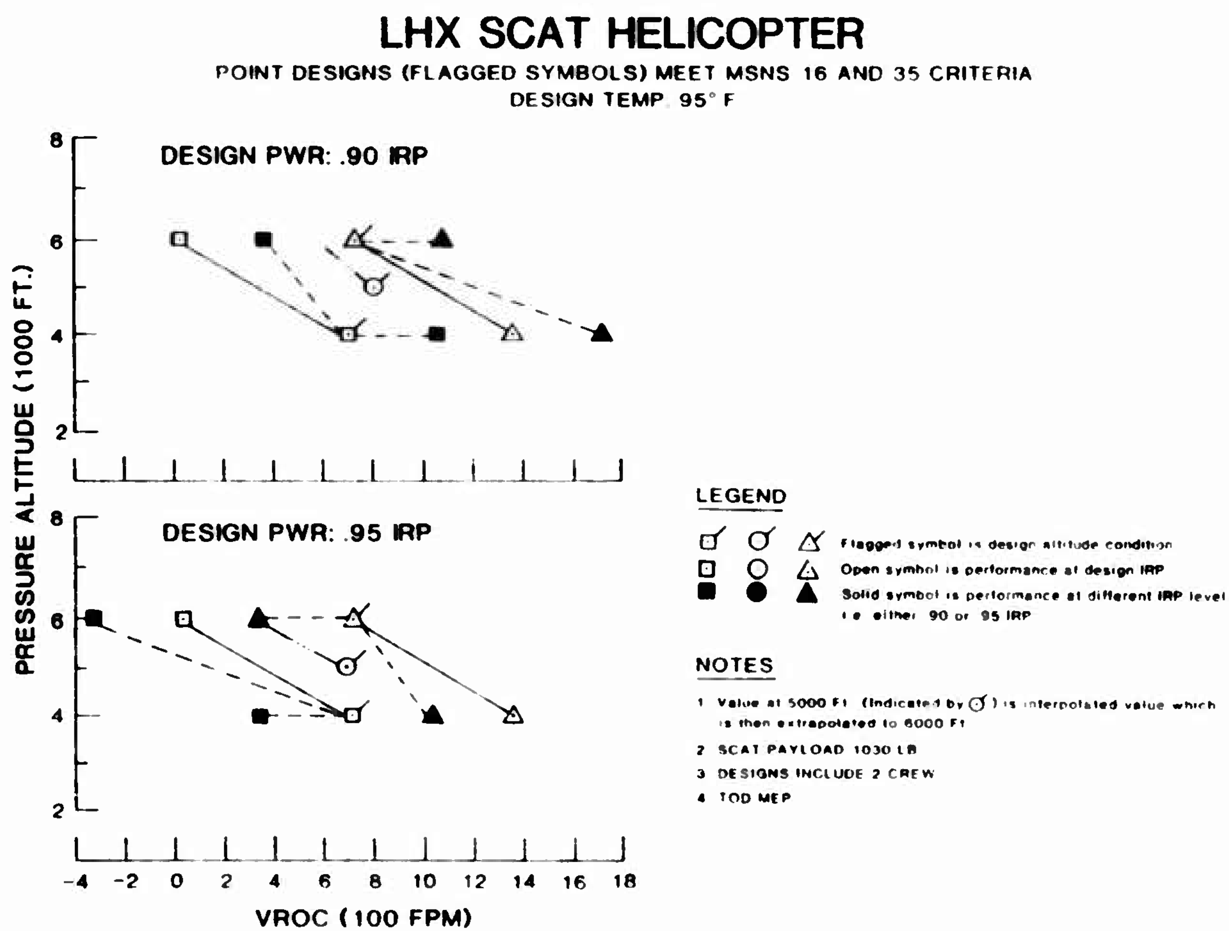

Figure N-IV-10. SCAT vertical flight, helicopter: .90 and .95 IRP.

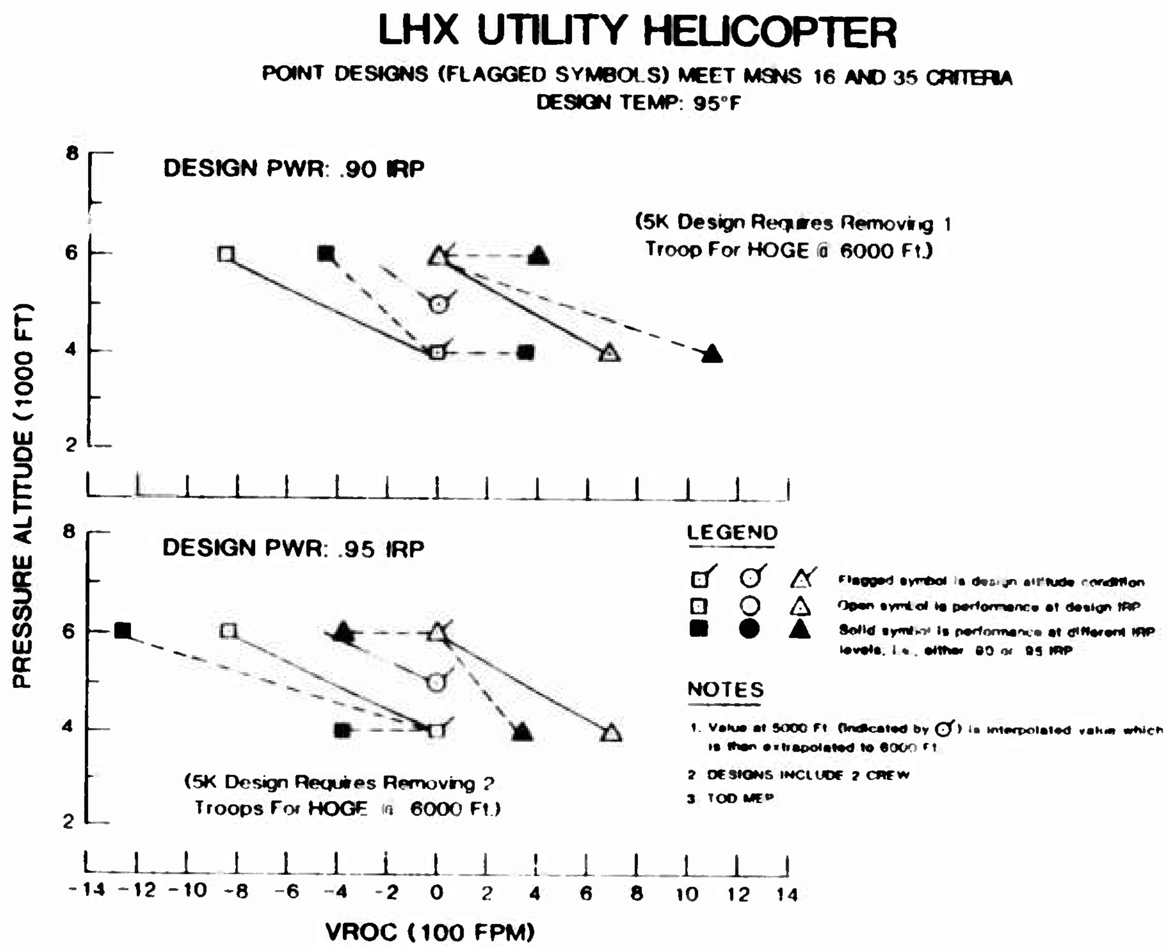

Figure N-IV-11. Utility vertical flight, helicopter: .90 and .95 IRP.

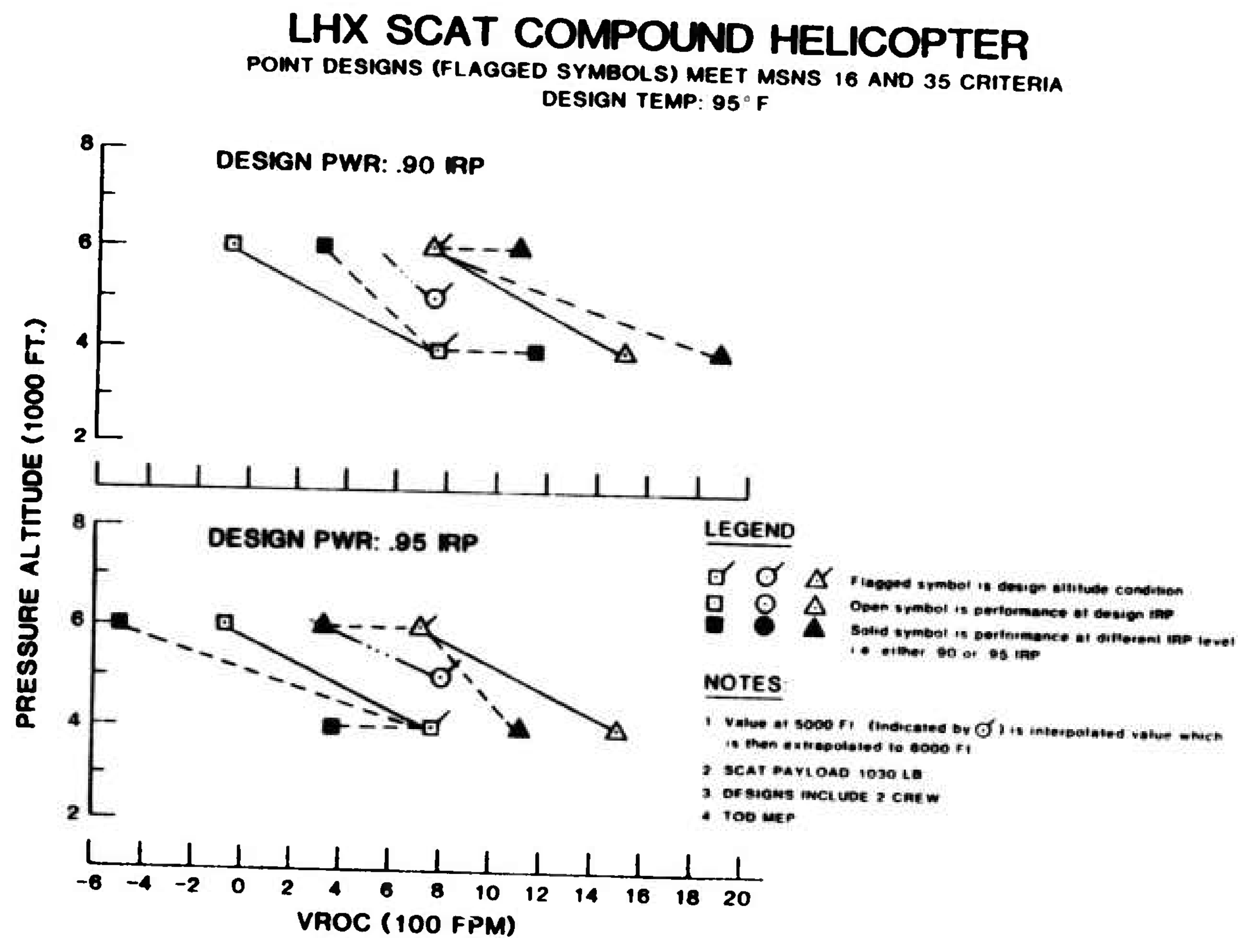

Figure N-IV-12. SCAT vertical flight, helicopter-compound: .90 and .95 IRP.

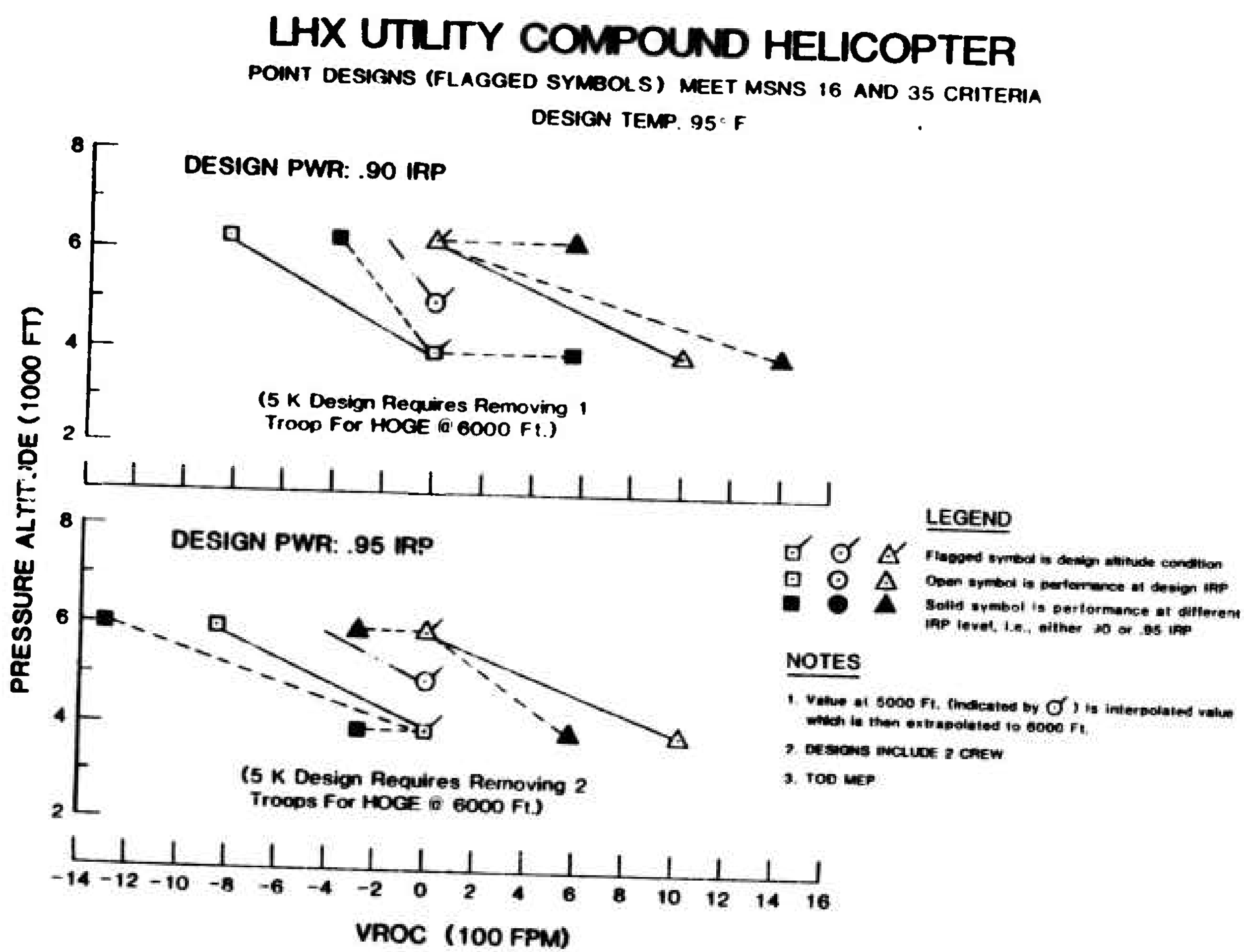

Figure N-IV-13. Utility vertical flight, helicopter-compound: .90 and .95 IRP.

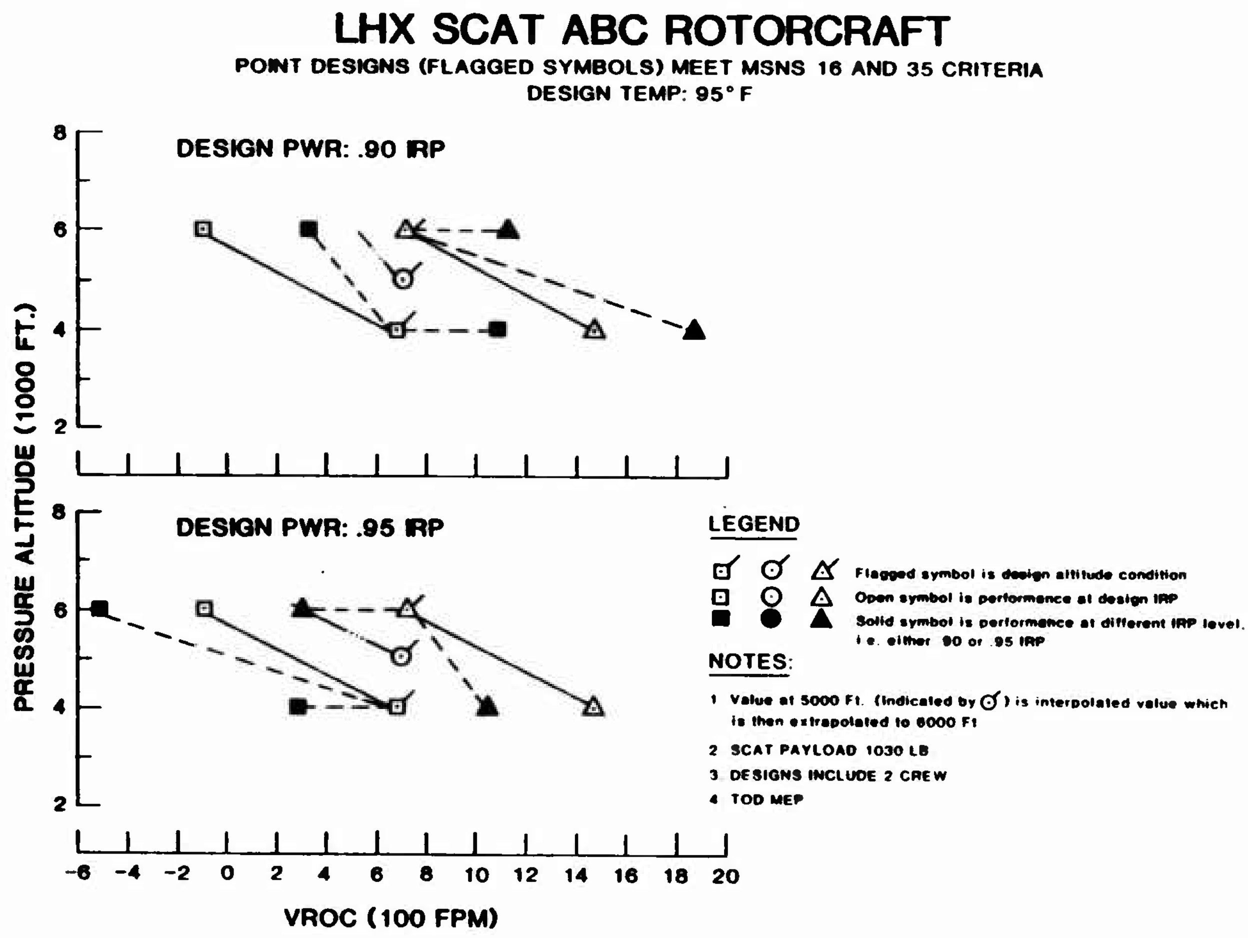

Figure N-IV-14. SCAT vertical flight, ABC: .90 and .95 IRP.

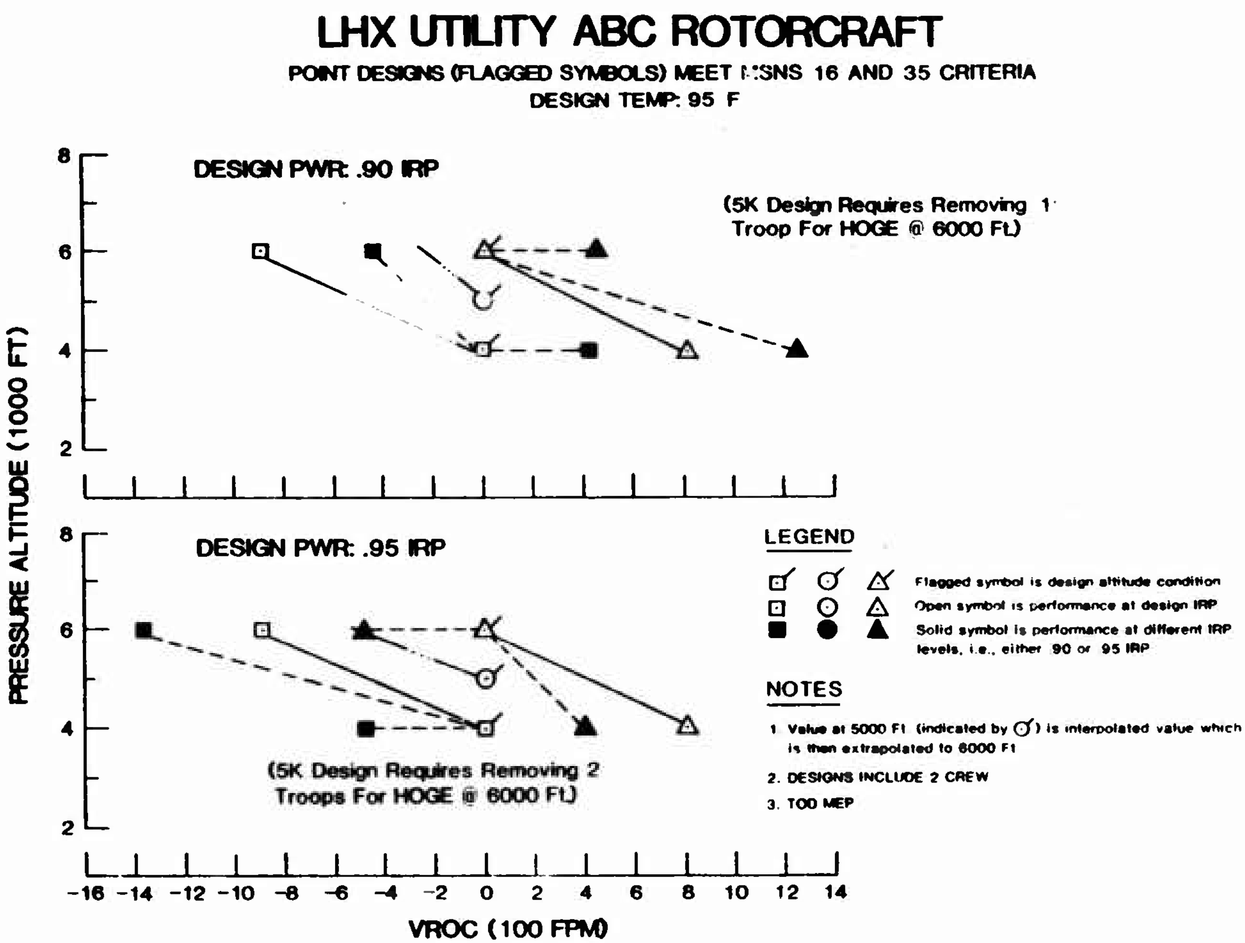

Figure N-IV-15. Utility vertical flight, ABC: .90 and .95 IRP.

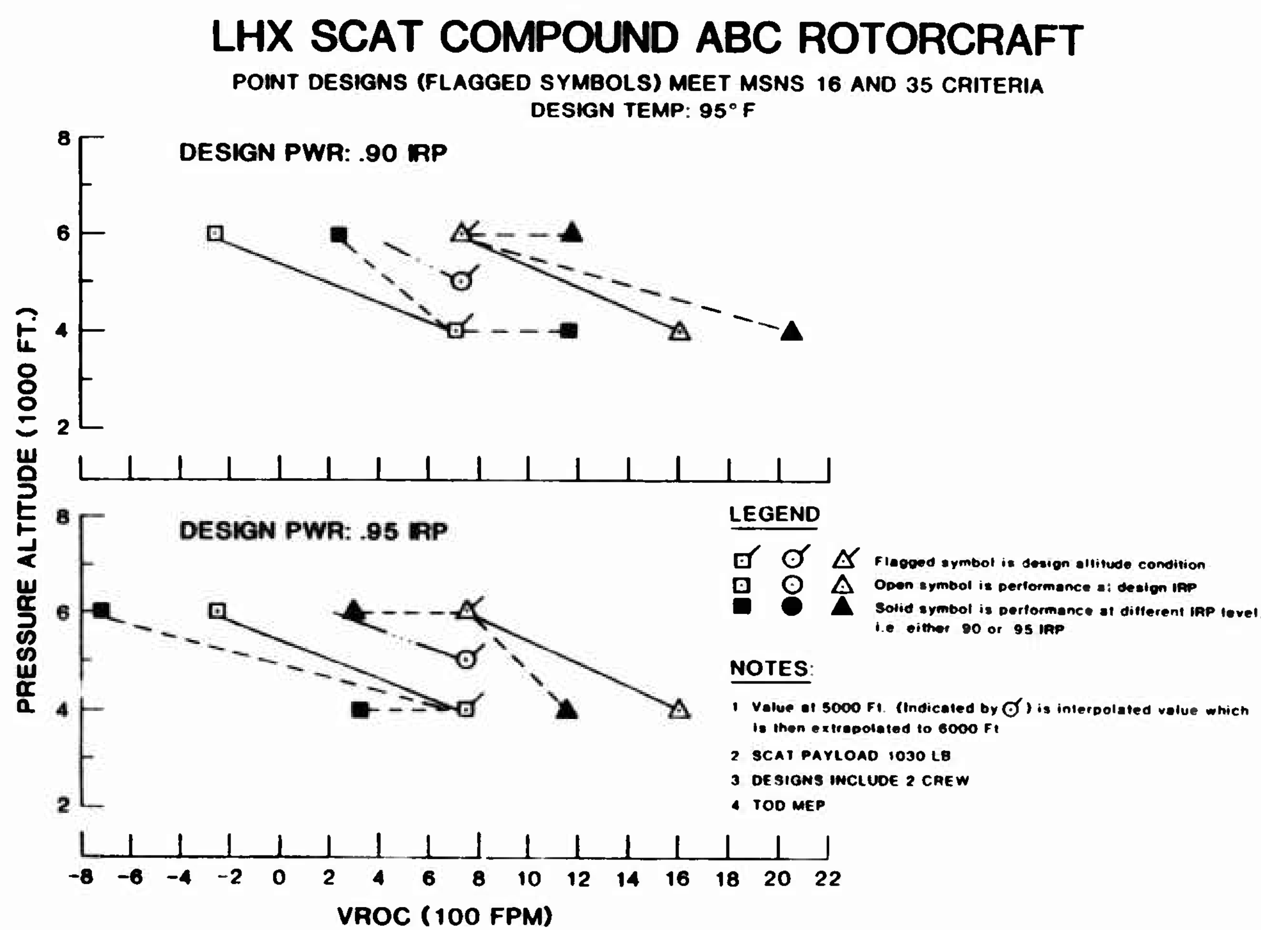

Figure N-IV-16. SCAT vertical flight, ABC-compound: .90 and .95 IRP.

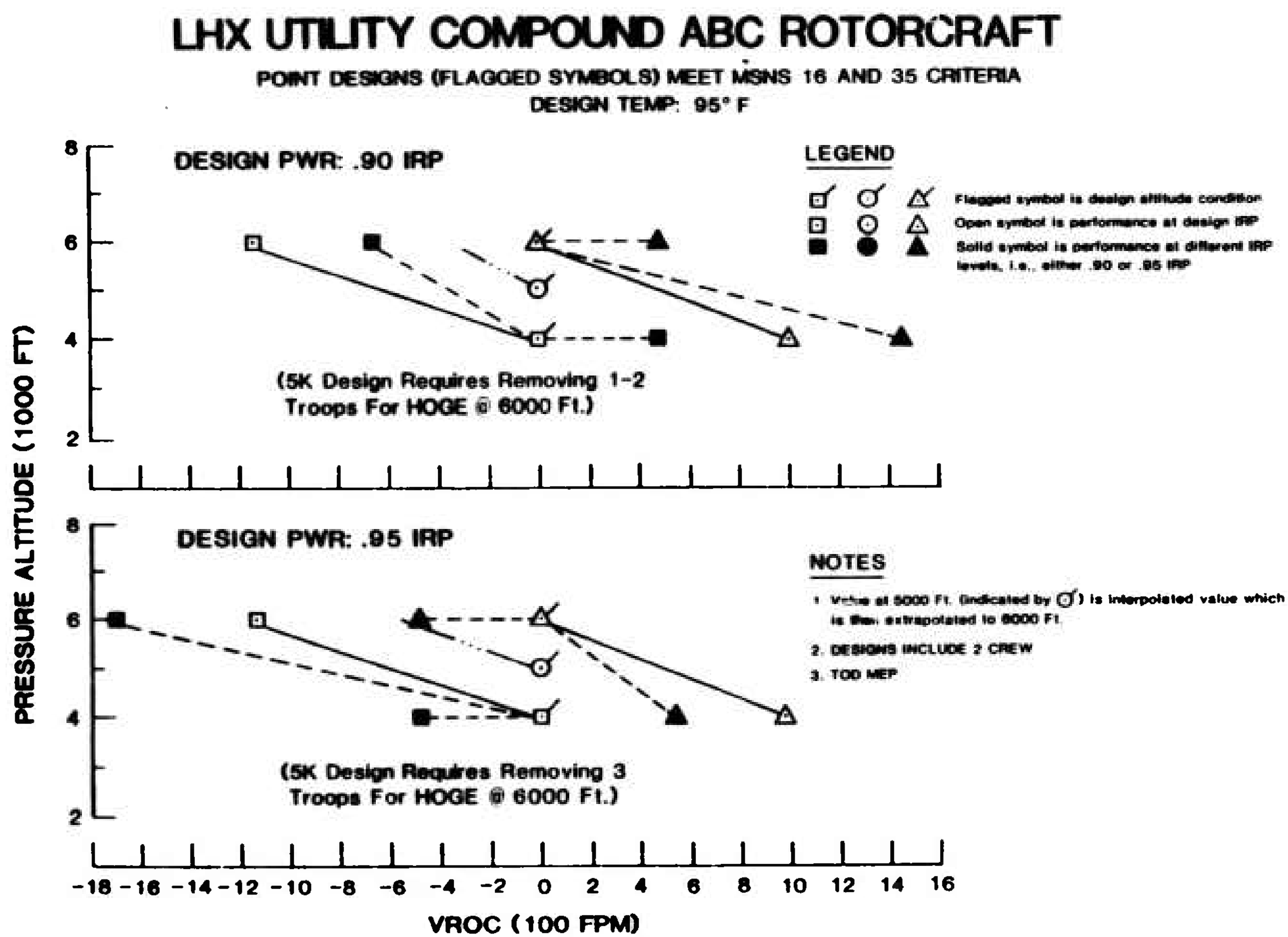

Figure N-IV-17. Utility vertical flight, ABC-compound: .90 and .95 IRP.

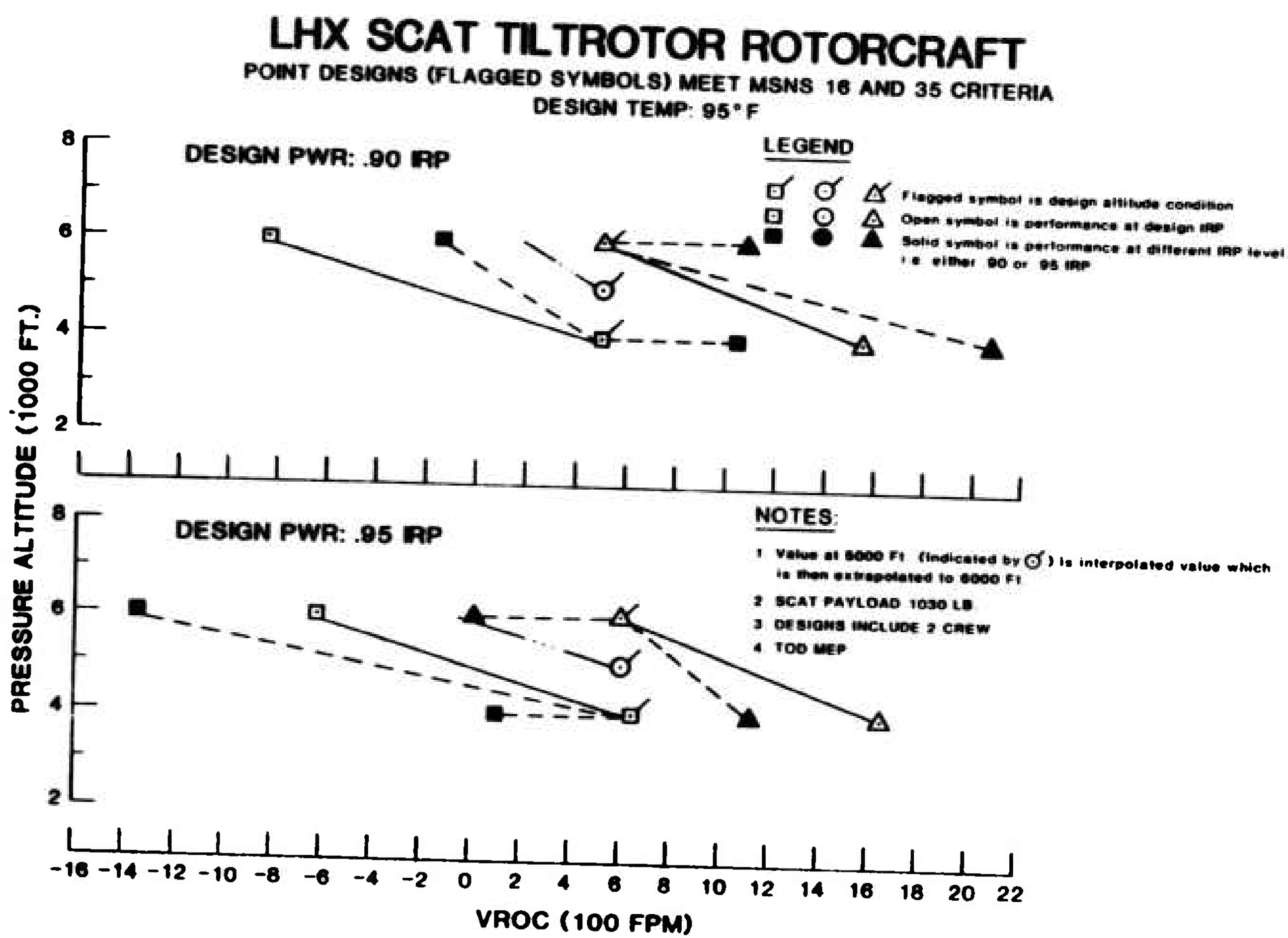

Figure N-IV-18. SCAT vertical flight, tilt rotor: .90 and .95 IRP.

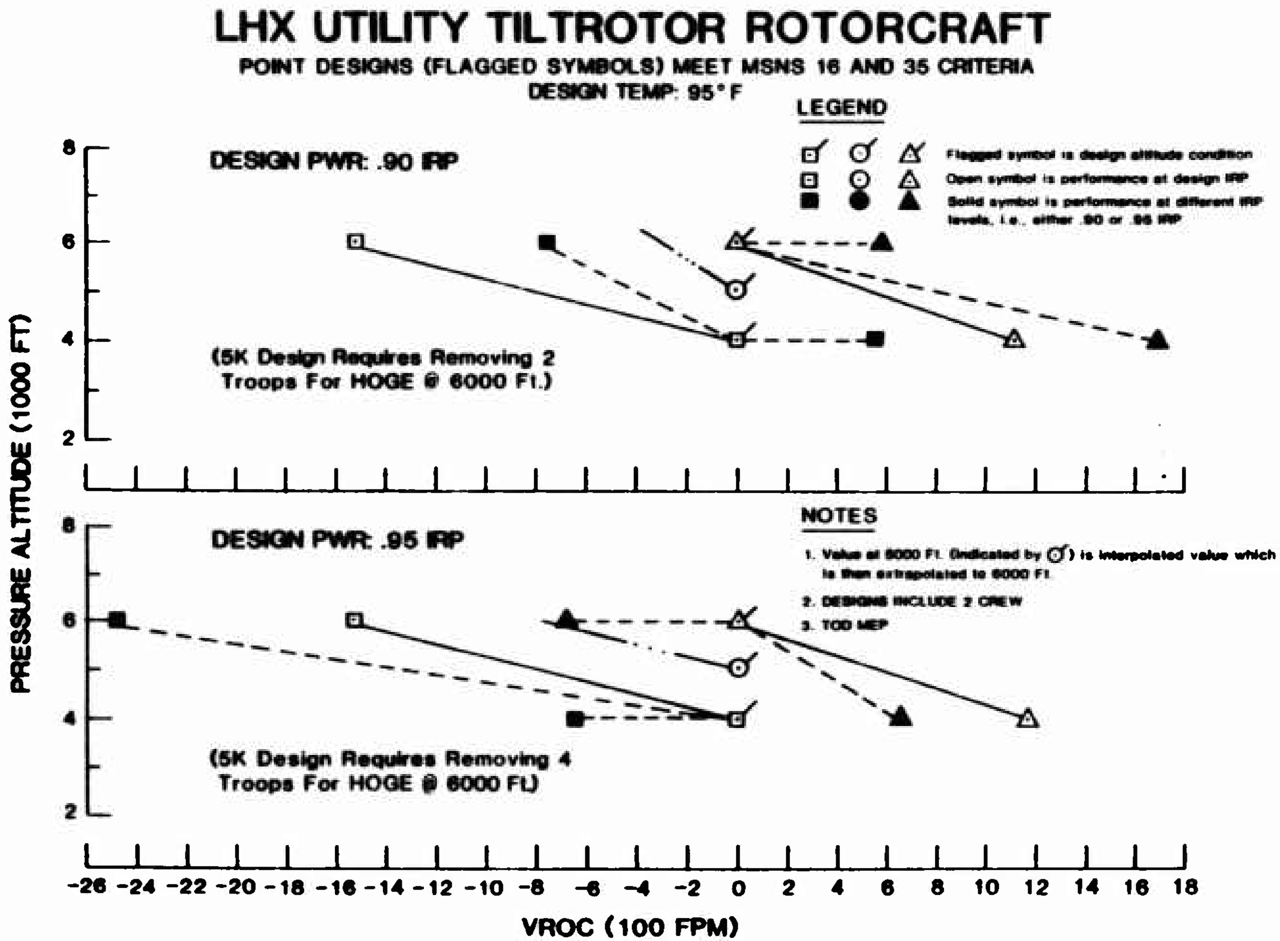

Figure N-IV-19. Utility vertical flight, tilt rotor: .90 and .95 IRP.

based on .90 IRP, it was found that the least cost approach to achieving respectable performance at 6,000 ft is to design the SCAT to 6,000 ft at .95 IRP with a fallout Utility as opposed to a .90 IRP design at 5,000 ft, operated at .95 IRP at 6,000 ft. The information for this comparison is presented in figure N-IV-21. It should be noted, however, that the full Utility payload (6 troops) at 6,000 ft can be realized for an additional .5-2.0 percent (depending on configuration) increase in gross weight and .25-2.5 percent (depending on configuration) increase in cost above those for a design at .95 IRP, 6,000 ft fallout Utility (comparison of figures N-IV-5 and N-IV-21).

c. Fixed Engine Size Designs. A possibility exists in the LHX program that an existing engine may be mandated before the TOA process is complete, or it may be mandated after the TOA. For this eventuality, SCAT designs were reviewed and a summary is presented in figure N-IV-22. Figure N-IV-22 presents the gross weight and altitude for which the design can maintain a 500-fpm VROC for a given engine size. Inspection of the data shows that the helicopter provides a higher operating altitude across the board for a given power level. This translates to increased effectiveness relative to the other designs. In an effort to quantify the advantage, a "comparative quality" index is proffered. The index addresses only those power levels for which there is a capability for other aircraft in addition to the helicopter. The cost data is derived from regressed cost data lines.

"Comparative Quality" Index =

(Wt Ratio) x (Vert Flt Alt Ratio) x (Cost Ratio)

where:

Wt. Ratio = (Wt. Hel)/(Wt. Other); > 1.00 = better than helo
< 1.00 = not as good as helo

Vertical Flight Altitude Ratio = (Oper. Alt Other)/(Oper. Alt Helo):
> 1.00 = better than helo
< 1.00 = not as good as helo

Cost Ratio = (Cost Helo)/(Cost Other); > 1.00 = better than helo
< 1.00 = not as good as helo

The relative comparison in terms of "comparative quality" are presented in figure N-IV-23. A value less than 1 indicates that the system does not give the highest altitude-vertical flight capability combination for the investment, all other aspects being equal. Inspection of the information in figure N-IV-23 shows that compared to the helicopter the other designs are significantly below the helicopter. For a mid-range power level of 1,200 horsepower, the only alternatives to a helicopter are compound helicopter and ABC, with the compound helicopter dropping out if the design power level is .90 IRP.

Design	.95 IRP				.90 IRP			
	SCAT		Utility		SCAT		Utility	
	P/L	VROC	P/L	VROC	P/L	VROC	P/L	VROC
HEL	1,030	350	4 Trp	HOGE	1,030	550	5 Trp	HOGE
HEL-C	1,030	420	4 Trp	HOGE	1,030	550	5 Trp	HOGE
ABC	1,030	320	4 Trp	HOGE	1,030	520	5 Trp	HOGE
ABC-C	1,030	300	3 Trp	HOGE	1,030	500	5 Trp	HOGE
TR	1,030	50	2 Trp	HOGE	1,030	170	4 Trp	HOGE

Figure N-IV-20. Capabilities of 5,000 ft designs operating at 6,000 ft. T = 95°F

Design	.95 IRP				.90 IRP			
	SCAT		Utility		SCAT		Utility	
	P/L	VROC	P/L	VROC	P/L	VROC	P/L	VROC
HEL	1,030	350	4 Trp	HOGE	1,030	550	5 Trp	HOGE
HEL-C	1,030	420	4 Trp	HOGE	1,030	550	5 Trp	HOGE
ABC	1,030	320	4 Trp	HOGE	1,030	520	5 Trp	HOGE
ABC-C	1,030	300	3 Trp	HOGE	1,030	500	5 Trp	HOGE
TR	1,030	50	2 Trp	HOGE	1,030	170	4 Trp	HOGE

Figure N-IV-21. Comparison of designs for 6,000 ft performance.

VROC = 500 fpm

2 Crew   1,288 lb MEP   Utility Fallout

Weapon Load = 1,030   Mission 16

Design IRP (%)	Engine Size SP/Eng @ SLS	Max SCAT GW and Altitude for Which VROC = 500 fpm HEL GW	HEL Alt	HEL-C GW	HEL-C Alt	ABC GW	ABC Alt	ABC-C GW	ABC-C Alt	TR GW	TR Alt
95	1,000	9,260	5,100	-	-	-	-	-	-	-	-
	1,050	9,400	5,700	-	-	-	-	-	-	-	-
	1,100	9,550	6,225	-	-	10,200	4,225	-	-	-	-
	1,150	9,700	6,750	-	-	10,300	4,900	-	-	-	-
	1,200	9,875	7,225	10,425	4,525	10,450	5,425	-	-	-	-
	1,250	10,000	7,675	10,600	5,125	10,600	5,875	-	-	10,860	4,350
	1,300	10,175	8,100	10,760	5,650	10,760	6,275	11,150	4,250	11,000	4,825
	1,350	10,350	8,450	10,925	6,075	10,960	6,675	11,350	4,650	11,140	5,300
	1,400	10,500	8,750	11,075	6,475	11,125	7,025	11,500	5,000	11,275	5,725

Figure N-IV-22. LHX SCAT designs (concluded on next page).

Design IRP (%)	Engine Size SP/Eng @ SLS	Max SCAT GW and Altitude for Which VROC = 500 fpm									
		HEL		HEL-C		ABC		ABC-C		TR	
		GW	Alt	GW	Alt	GW	Alt	GW	Alt	GW	Alt
90	1,000	9,200	4,200	-	-	-	-	-	-	-	-
	1,050	9,350	4,825	-	-	-	-	-	-	-	-
	1,100	9,480	5,375	-	-	-	-	-	-	-	-
	1,150	9,640	5,875	-	-	-	-	-	-	-	-
	1,200	9,775	6,375	-	-	10,400	4,450	-	-	-	-
	1,250	9,925	6,825	-	-	10,525	5,025	-	-	-	-
	1,300	10,080	7,275	10,640	5,600	10,660	5,475	-	-	-	-
	1,350	10,240	7,700	10,775	5,150	10,840	5,875	-	-	11,050	4,375
	1,400	10,400	8,100	10,975	5,600	11,000	6,250	11,400	4,125	11,180	4,825

Figure N-IV-22. (concluded)

VROC = 500 fpm	2 Crew	1,288 lb MEP	Weapon Load = 1,030			
Mission 16			Utility Fallout			
Design IRP (%)	Engine Size SIP/Eng @ SLS	Comparative Quality Index				
		HEL	HEL-C	ABC	ABC-C	TR
95	1,000	1.0	-	-	-	-
	1,050	1.0	-	-	-	-
	1,100	1.0	-	.61	-	-
	1,150	1.0	-	.66	-	-
	1,200	1.0	.58	.69	-	-
	1,250	1.0	.62	.70	-	.51
	1,300	1.0	.65	.71	.46	.53
	1,350	1.0	.67	.72	.48	.57
	1,400	1.0	.69	.73	.50	.59
90	1,000	1.0	-	-	-	-
	1,050	1.0	-	-	-	-
	1,100	1.0	-	-	-	-
	1,150	1.0	-	-	-	-
	1,200	1.0	-	.63	-	-
	1,250	1.0	-	.67	-	-
	1,300	1.0	.59	.69	-	-
	1,350	1.0	.62	.70	-	.51
	1,400	1.0	.64	.71	.44	.54

Figure N-IV-23. Relative comparison of LHX-SCAT designs for fixed engine size.

N-IV-6. FINDINGS.

a. A SCAT designed to 500 fpm VROC at 6,000 ft at .95 IRP results in a Utility fallout with a HOGE payload capability of five troops for a lower penalty in weight and cost than designing a balanced SCAT and Utility at 5,000 ft, .90 IRP and operating at 6,000 ft, .95 IRP.

b. For an additional .5 to 2.0 percent increase (depending on configuration) in gross weight and .25 to 2.5 percent increase (depending on configuration) in cost, full Utility payload capability can be achieved at 6,000 ft, i.e., six troops.

c. Designing to 8,000 ft/95°F results in increases in weight and cost generally greater than 10 percent above designs based on 4,000 ft/95°F.

d. The UTTAS and Army Helicopter Improvement Program (AHIP) COEA reports substantiated the need to design to 6,000 ft/95°F.

e. If the engine size is fixed, the helicopter gives the best altitude-vertical flight capability combination for the investment.

N-IV-7. CONCLUSIONS.

a. It is possible to develop a SCAT with a 500 fpm VROC at 6,000 ft/95°F for a 4-5 percent increase in mission gross weight over a design at 4,000 ft. The increase in unit flyaway costs would range from 2 to 4 percent. The fallout Utility would have a payload of approximately five troops and two Stinger air-to-air missiles. The increase in the Utility mission gross weight is approximately 1 to 4 percent with an associated unit flyaway cost of between 2 and 5 percent. The ranges are configuration-driven.

b. For a 4-6 percent increase in weight and 3-5 percent increase in cost, full capability for both the SCAT and Utility at 6,000 ft/95°F can be obtained.

c. For a fixed engine size, the helicopter delivers a better altitude-vertical flight capability combination than any of the other designs.

d. The helicopter is the lowest cost system to achieve increased altitude-vertical flight capability.

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ANNEX V TO APPENDIX N

MANEUVERABILITY/AGILITY (M/A) ANALYSIS

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ANNEX V TO APPENDIX N

MANEUVERABILITY/AGILITY (M/A) ANALYSIS

N-V-1. PURPOSE. To investigate the differences in maneuverability/agility (M/A) characteristics among the different configurations.

N-V-2. BACKGROUND. An intent of the Light Helicopter Family (LHX) program is to develop a "highly" maneuverable/agile rotorcraft which would enhance mission effectiveness through the synergistic effect of flight characteristics and expected increased survivability.

N-V-3. LIMITATIONS.

a. This subanalysis will address Scout-Attack (SCAT) and Utility candidates based on derivatives of existing rotorcraft and new design rotorcraft. The derivative rotorcraft are the Sikorsky S75 and the Agusta A129. The new designs include a helicopter, compound helicopter, advancing blade concept (ABC), compound ABC, and a tilt rotor (TR).

b. Comparisons to the existing fleet of Army helicopters are not within the purview of a trade-off analysis (TOA) but are the responsibility of the cost and operational effectiveness analysis (COEA).

c. The ambient conditions examined are 4,000 feet (ft)/95° Fahrenheit (F) and 2,000 ft/70°F.

d. Comparisons are made at the design mission gross weight values per the trade-off determination (TOD) data base.

N-V-4. METHODOLOGY. Maneuverability in this analysis is defined as the capability to change the flight path of the system in a controlled manner. Agility is defined as the rapidity with which the change to flight path command is affected. The maneuverability parameters include rate of climb, rate of descent, and turn radius. The agility parameters include longitudinal acceleration, longitudinal deceleration, and turn rate. All parameter comparisons are based on steady state or sustained levels. The reason for this is the fact that M/A requirements in the combat environment for the LHX have not been postulated beyond the desired need for a ". . . . highly maneuverable and agile rotorcraft" to replace the aging UH-1, AH-1, and OH-58 type aircraft. As the LHX program progresses into the COEA phase, perhaps the requirements will be more specifically defined. A quantitative ranking scheme is used to determine which design(s) are preferred. The scheme is presented in section N-V-5. This analysis does not attempt to integrate the synergism of other aircraft characteristics in determining which design is preferred. The analysis is based on the information provided by the TOD. This analysis addresses the M/A for the SCAT and Utility at 4,000 ft/95°F first, followed by an analysis of their capabilities at 2,000 ft/70°F.

N-V-5. RESULTS/ANALYSIS.

a. SCAT Designs (4,000 ft/95°F).

(1) The maneuverability and agility characteristics for the SCAT at 4,000 ft/95°F are presented in figures N-V-1 through N-V-24. The data in the figures depict the absolute relationships between the various types of rotorcraft. For purposes of analysis, the data has been reduced to normalized values relative to the helicopter, i.e., establishing the helicopter value as the benchmark, how do each of the other designs compare? These data comparisons are presented in figures N-V-25 through N-V-48. The evaluation was conducted by comparing M/A parameters over speed. During the analysis, it became clear that the designs should be evaluated in three speed bands. The bands are somewhat synonymous with but not the same as terrain flight modes and are: 0-40 knots (kt) (nap-of-the-earth (NOE)), +40-120 kt (contour), and above 120 kt (low level). The reader is cautioned that these intervals are dependent on the ambient conditions and that the interpretation for speed intervals within reasonable limits is the prerogative of the analyst. It should be noted that the technique of normalization could mask the relevance of the data being treated, i.e., although one design may have a higher normalized value than another, the absolute value of both may or may not be acceptable. However, the levels of maneuverability and agility inherent in the TOD baseline designs were specified as being consistent with the currently perceived level of technology that would exist in the production time frame. Also, this is not to say that trade-offs cannot be made to enhance M/A. The results from simulation models used to evaluate M/A presented elsewhere in the performance report address this possibility.

(2) Longitudinal acceleration. Figures N-V-25 through N-V-28 presents the longitudinal acceleration of the five preliminary design concepts, normalized to the helicopter. Longitudinal acceleration capability is considered to be vitally important in the speed range for best endurance which is the loiter speed band and at which specific excess power potential is maximized, which translates to improved chances of evading or engaging a threat. Specific excess power is discussed in paragraph (7), page N-V-19. Inspection of the data shows that in the 0-40 kt region the helicopter would be preferred over the ABC as it is consistent. The other three designs would rank equally behind the helicopter and ABC. In the 40-120 kt interval, the order of preference would be TR, helicopter, ABC, and compound helicopter designs, equally. Above 120 kt, the ranking would be TR, compound ABC, helicopter/ABC, and compound helicopter. Helicopter/ABC means both are equal in ranking. On the basis of the information, the conclusions are that the helicopter is the preferred system in the 0-40 kt interval and that the TR is preferred above 40 kt. In overall perspective, the TR would be the preferred system because at the best endurance speed of the helicopter, the TR would be 30 to 40 percent better than the helicopter and, as stated above, this would provide an inherent survivability advantage. Other aspects such as aircraft signature, aircraft survivability equipment (ASE) suite effectiveness, vulnerability, and armament, etc., are not included.

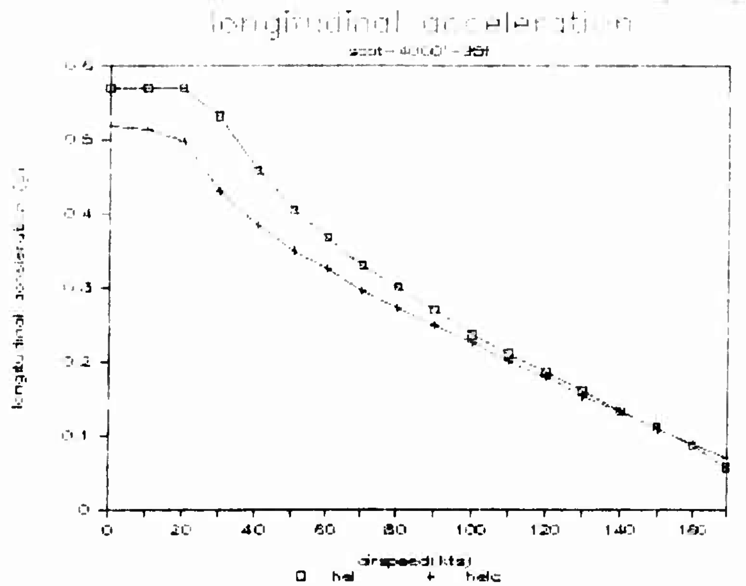

Figure N-V-1. SCAT longitudinal acceleration: helicopter and helicopter-compound, 4,000 ft, 95°F.

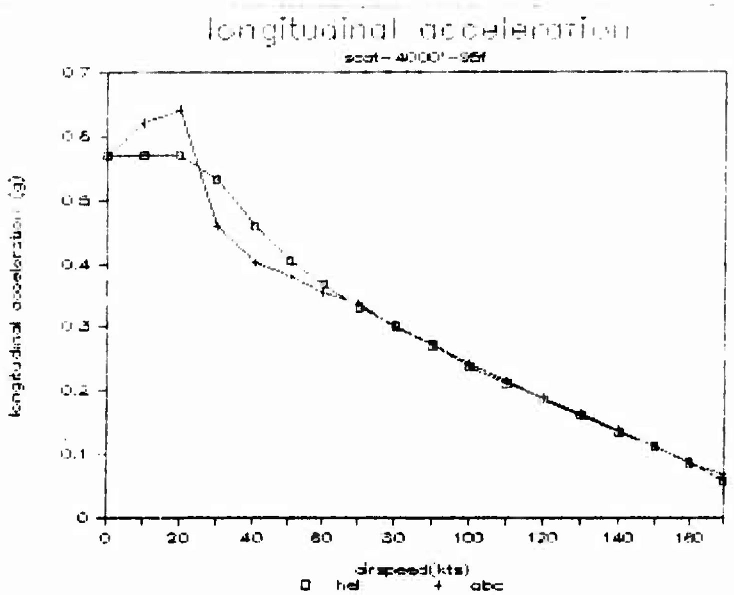

Figure N-V-2. SCAT longitudinal acceleration: helicopter and ABC, 4,000 ft, 95°F.

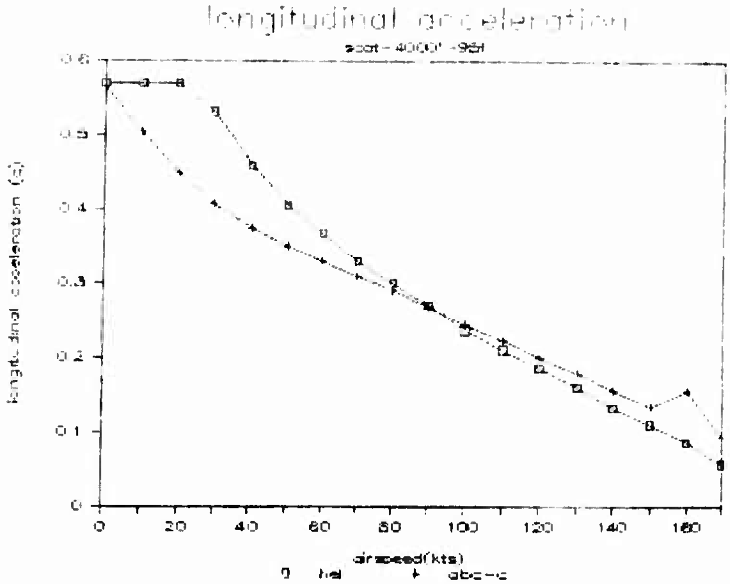

Figure N-V-3. **SCAT longitudinal acceleration: helicopter and ABC-compound, 4,000 ft, 95°F.**

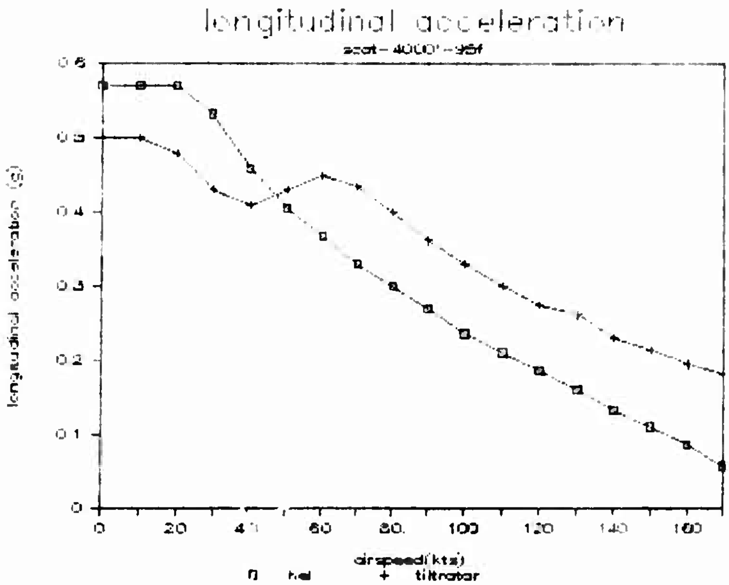

Figure N-V-4. **SCAT longitudinal acceleration: helicopter and tilt rotor, 4,000 ft, 95°F.**

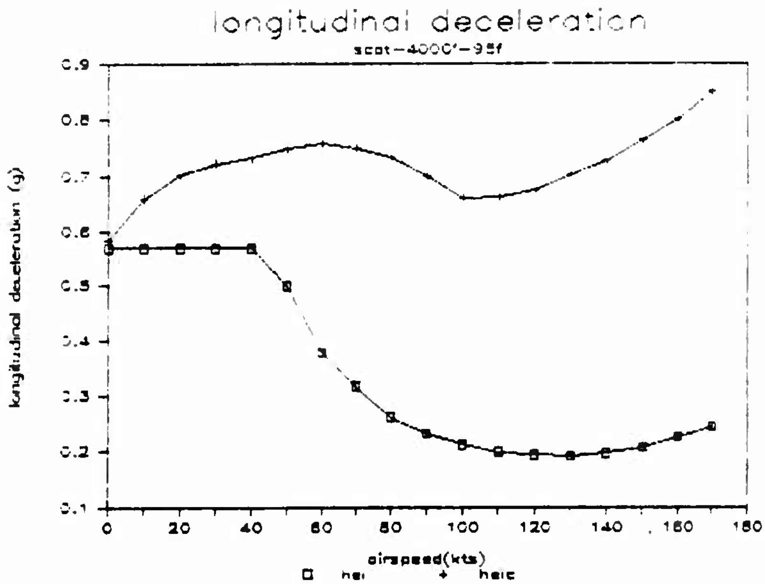

Figure N-V-5. SCAT longitudinal deceleration: helicopter and helicopter-compound, 4,000 ft, 95°F.

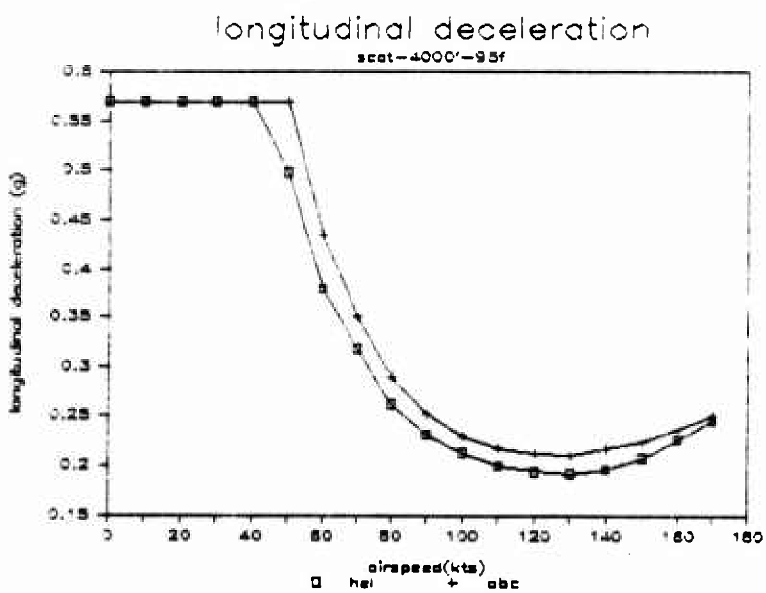

Figure N-V-6. SCAT longitudinal deceleration: helicopter and ABC, 4,000 ft, 95°F.

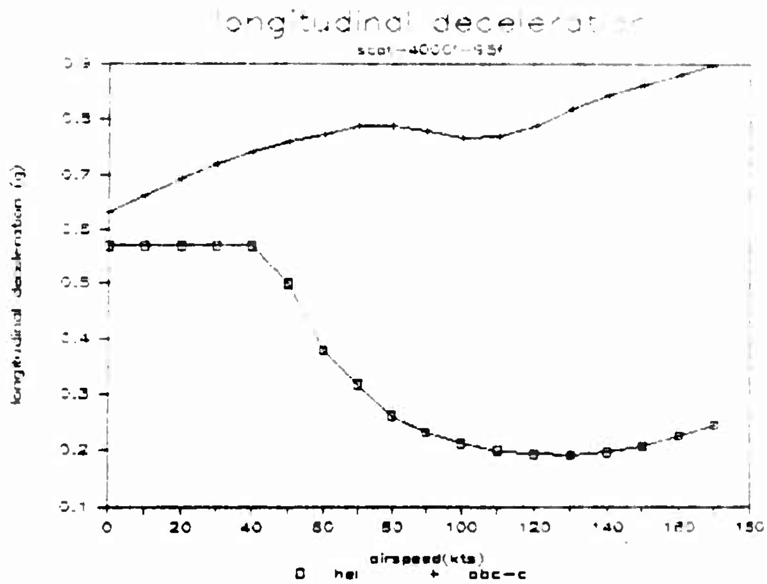

Figure N-V-7. SCAT longitudinal deceleration: helicopter and ABC-compound, 4,000 ft, 95°F.

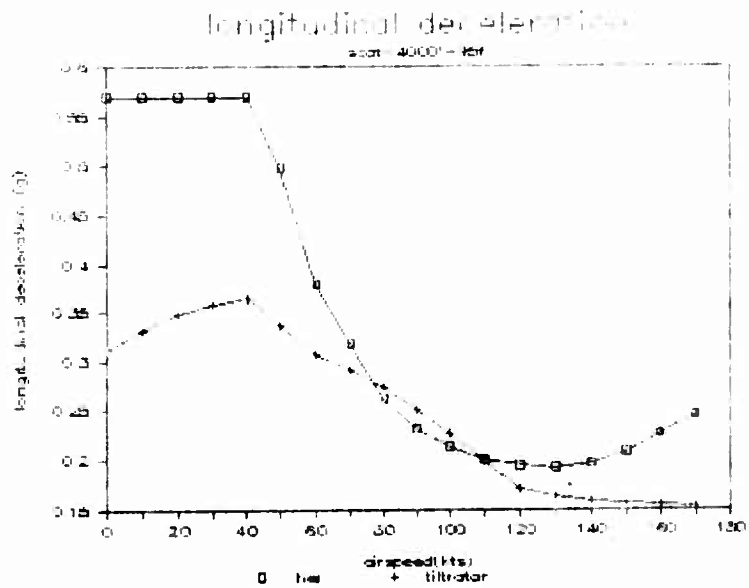

Figure N-V-8. SCAT longitudinal deceleration: helicopter and tilt rotor, 4,000 ft, 95°F.

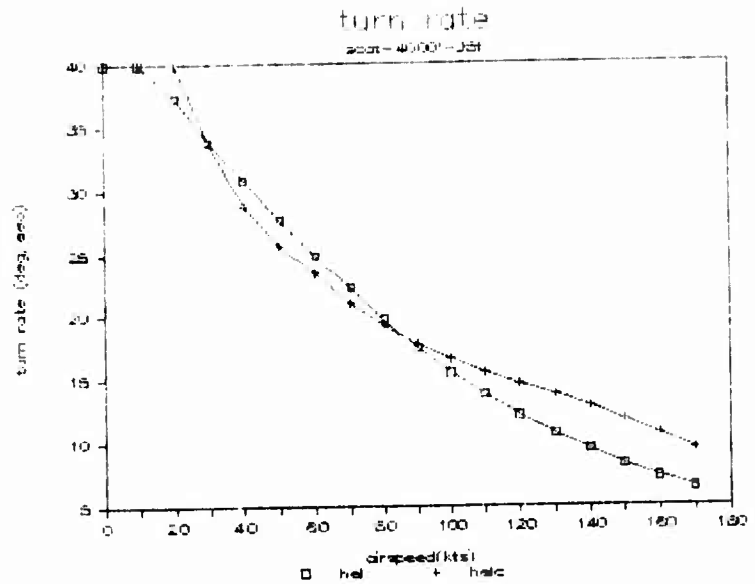

Figure N-V-9. SCAT turn rate: helicopter and helicopter-compound, 4,000 ft, 95°F.

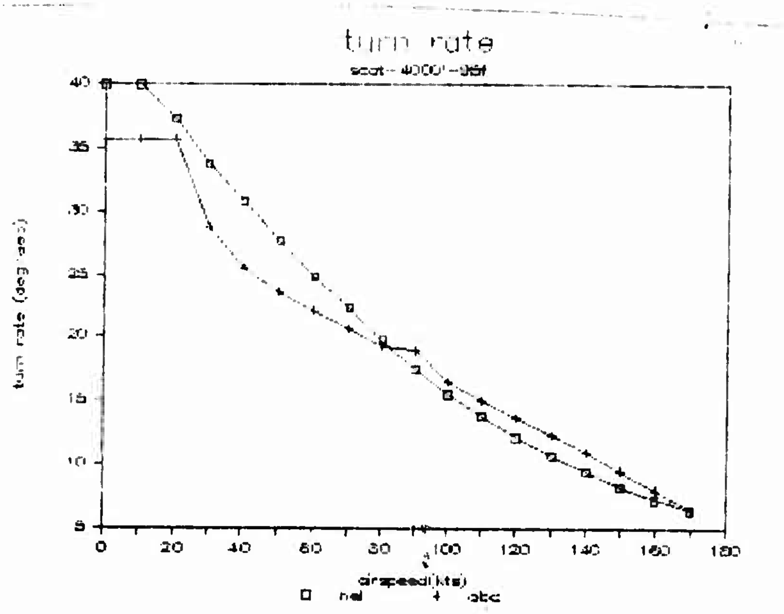

Figure N-V-10. SCAT turn rate: helicopter and ABC, 4,000 ft, 95°F.

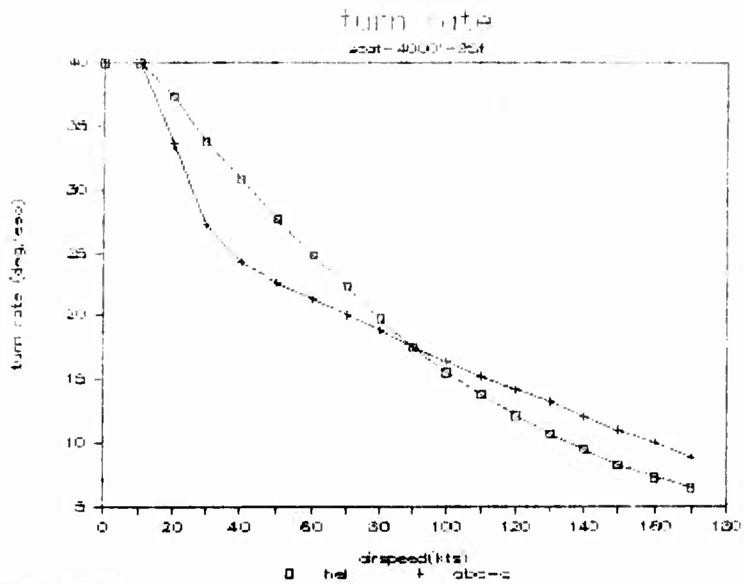

Figure N-V-11. SCAT turn rate: helicopter and ABC-compound, 4,000 ft, 95°F.

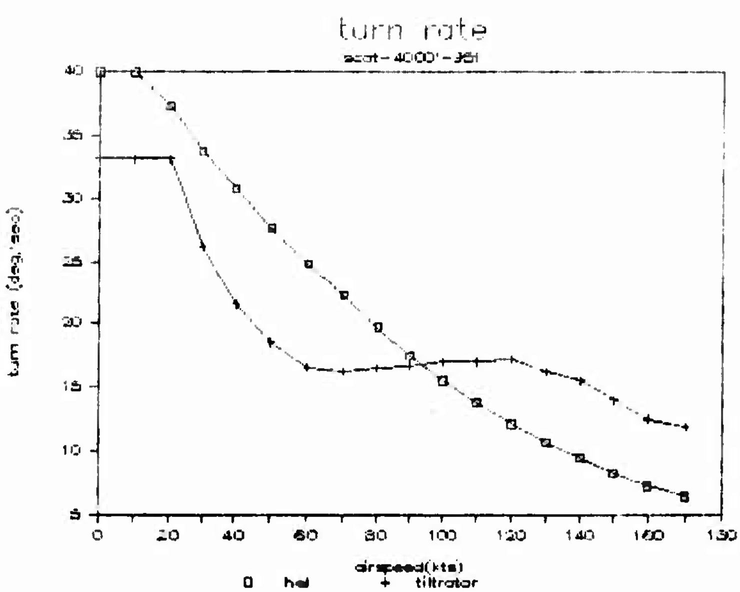

Figure N-V-12. SCAT turn rate: helicopter and tilt rotor, 4,000 ft, 95°F.

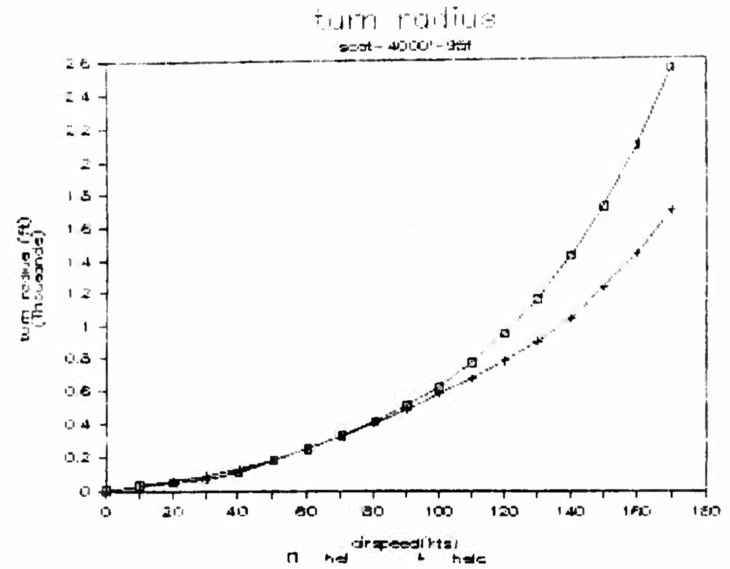

Figure N-V-13. SCAT turn radius: helicopter and helicopter-compound, 4,000 ft, 95°F.

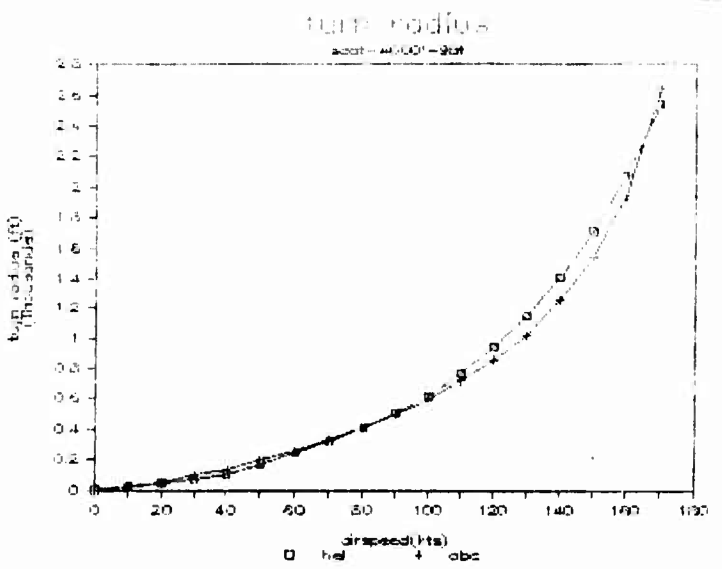

Figure N-V-14. SCAT turn radius: helicopter and ABC, 4,000 ft, 95°F.

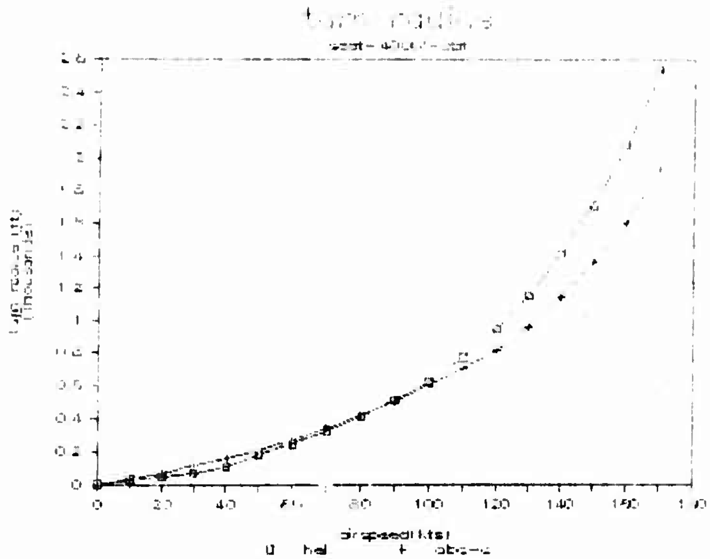

Figure N-V-15. SCAT turn radius: helicopter and ABC-compound, 4,000 ft, 95°F.

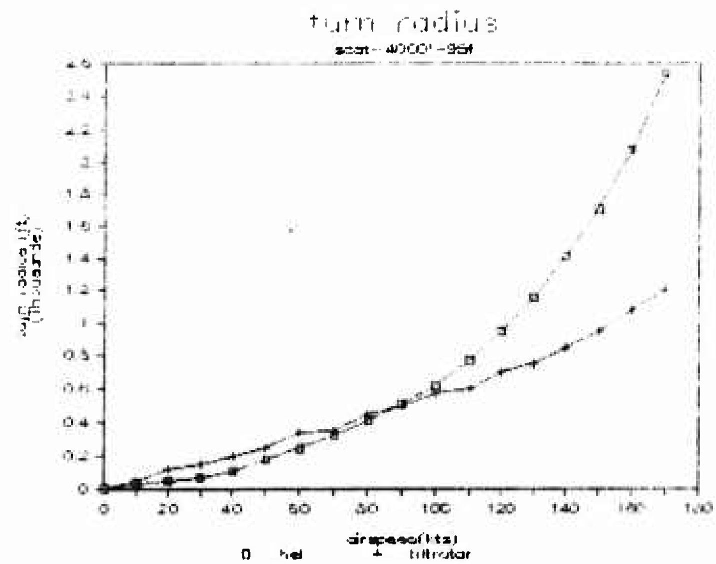

Figure N-V-16. SCAT turn radius: helicopter and tilt rotor, 4,000 ft, 95°F.

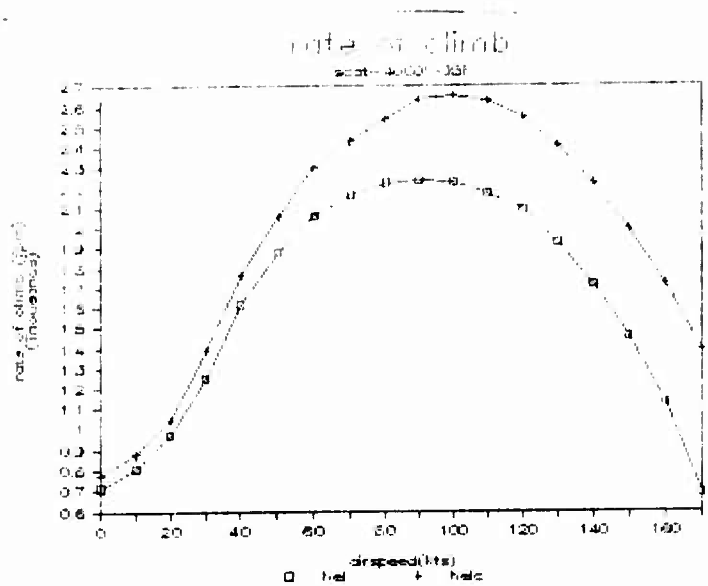

Figure N-V-17. SCAT climb rate: helicopter and helicopter-compound, 4,000 ft, 95°F.

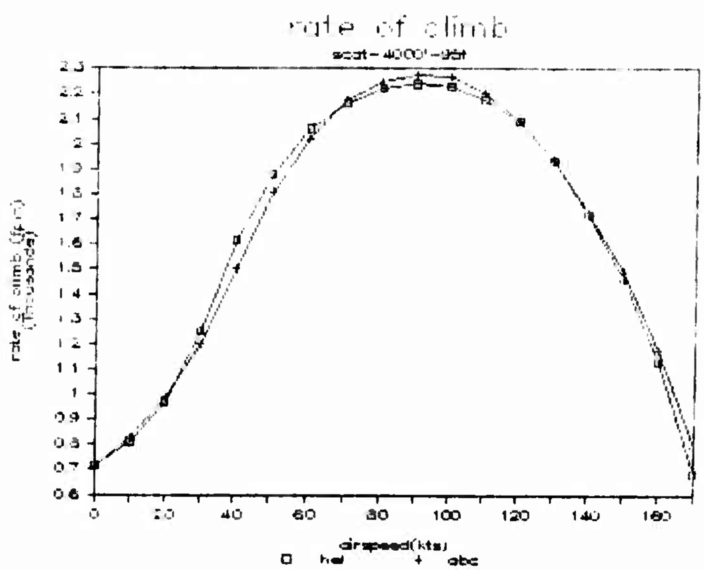

Figure N-V-18. SCAT climb rate: helicopter and ABC, 4,000 ft, 95°F.

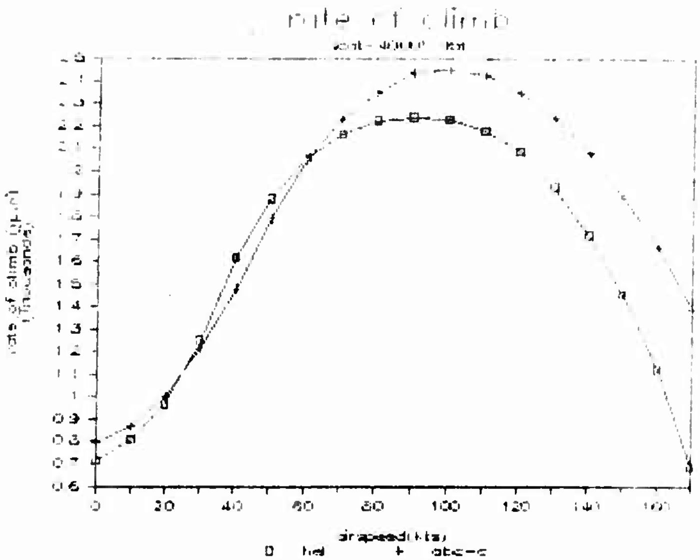

Figure N-V-19. SCAT climb rate: helicopter and ABC-compound, 4,000 ft, 95°F.

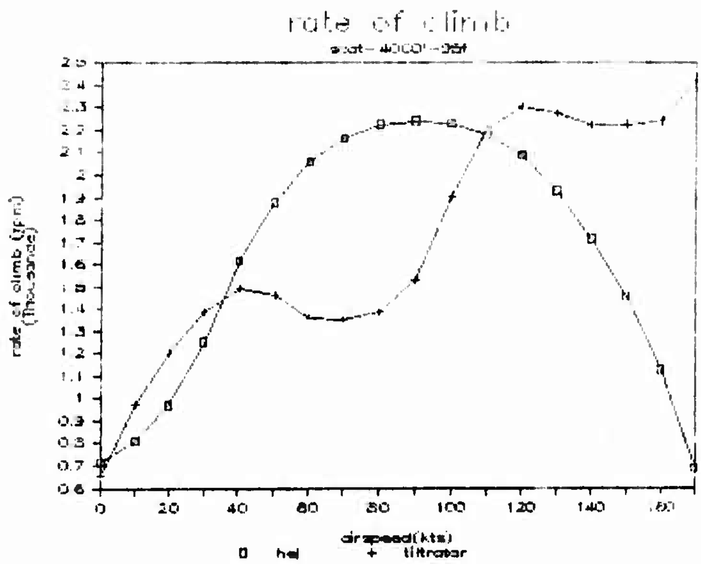

Figure N-V-20. SCAT climb rate: helicopter and tilt rotor, 4,000 ft, 95°F.

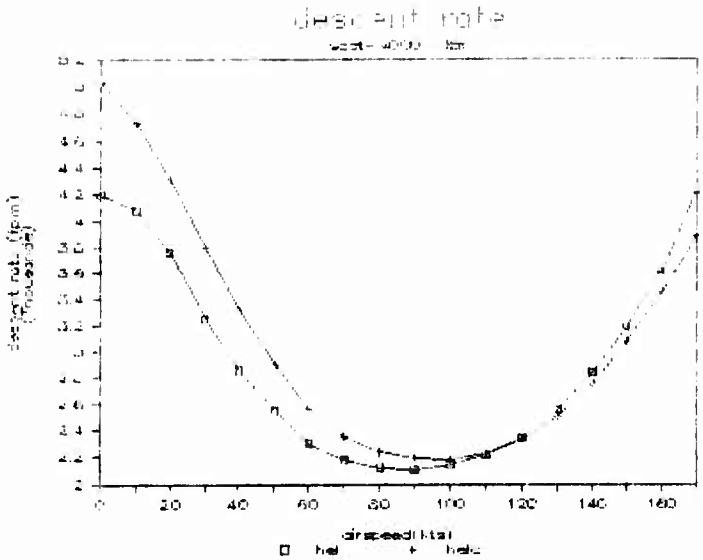

Figure N-V-21. SCAT descent rate: helicopter and helicopter-compound, 4,000 ft, 95°F.

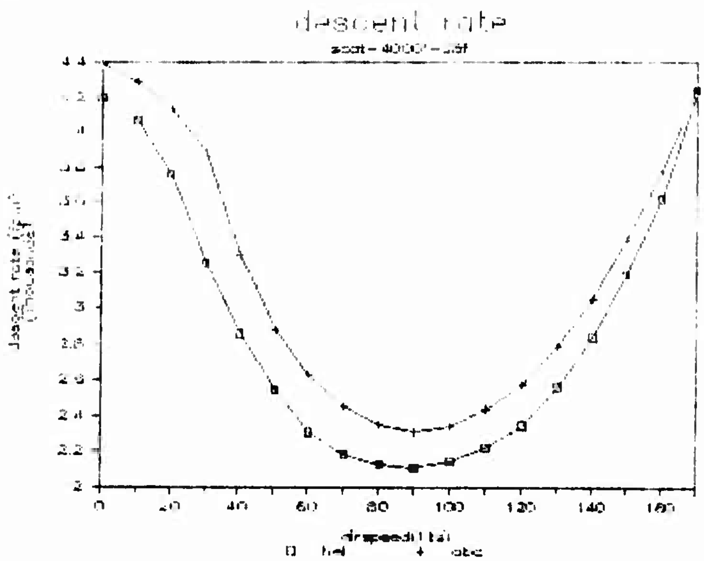

Figure N-V-22. SCAT descent rate: helicopter and ABC, 4,000 ft, 95°F.

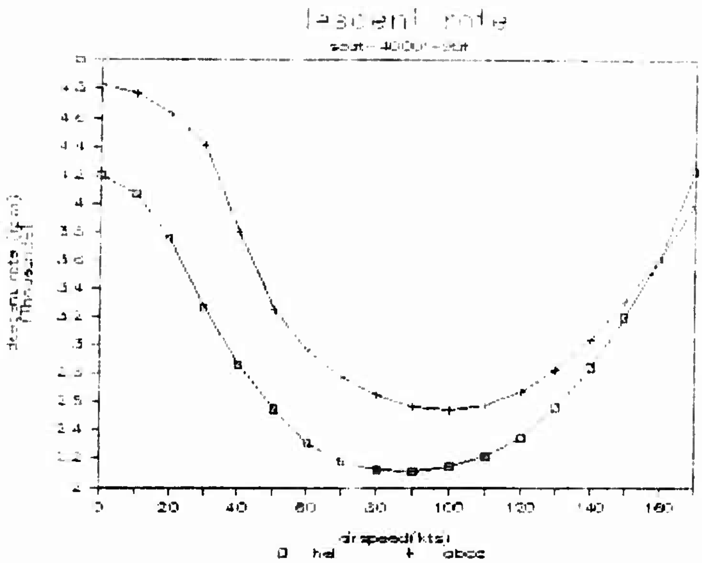

Figure N-V-23. SCAT descent rate: helicopter and ABC-compound, 4,000 ft, 95°F.

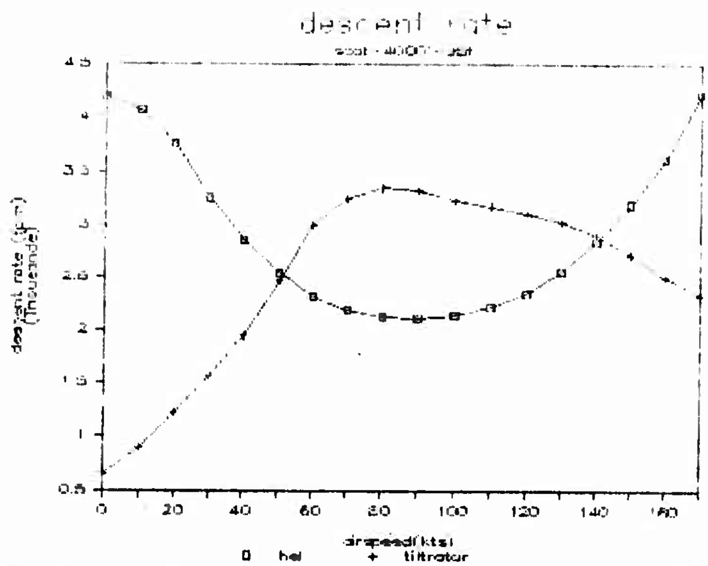

Figure N-V-24. SCAT descent rate: helicopter and tilt rotor, 4,000 ft, 95°F.

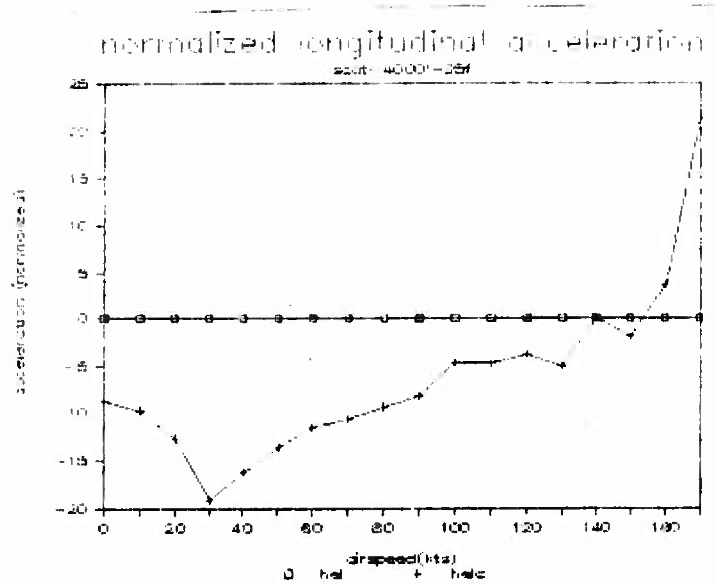

Figure N-V-25. SCAT normalized longitudinal acceleration: helicopter and helicopter-compound, 4,000 ft, 95°F.

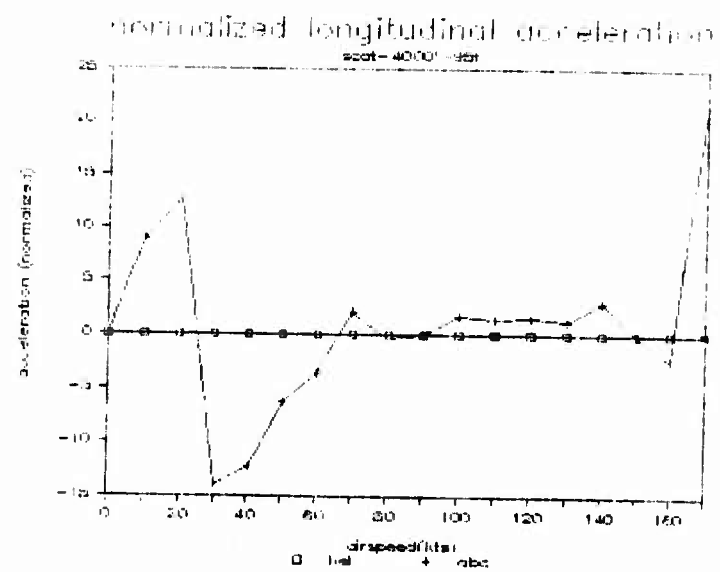

Figure N-V-26. SCAT normalized longitudinal acceleration: helicopter and ABC, 4,000 ft, 95°F.

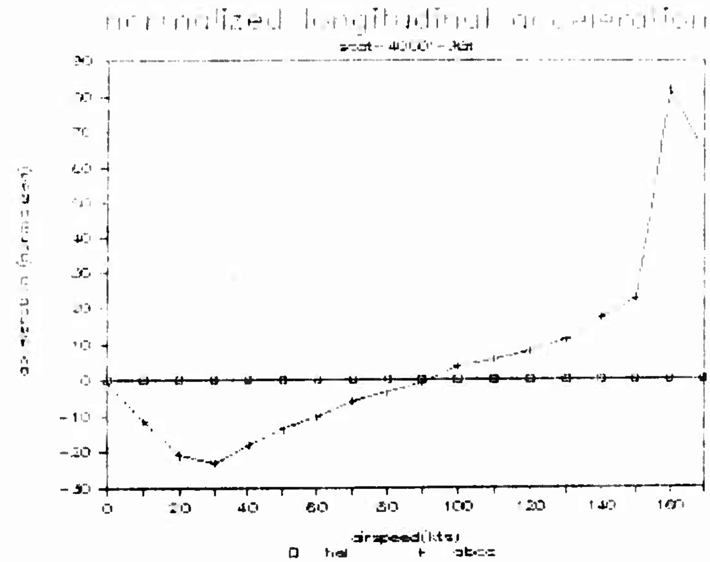

Figure N-V-27. SCAT normalized longitudinal acceleration: helicopter and ABC-compound, 4,000 ft, 95°F.

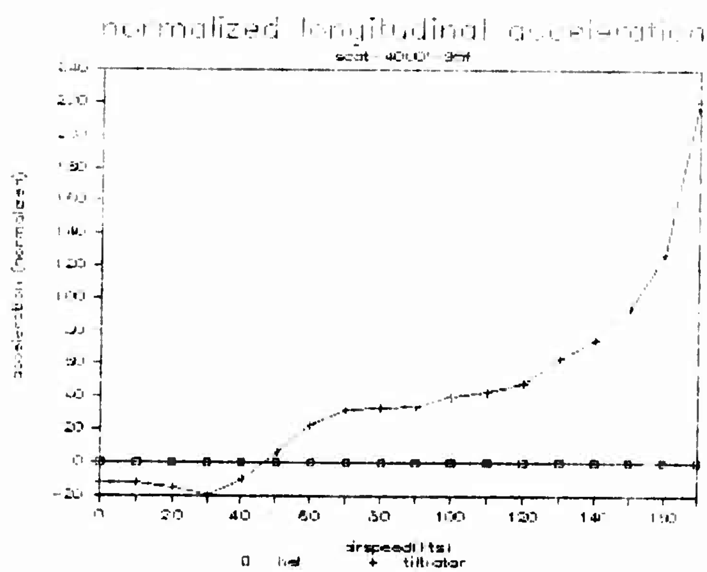

Figure N-V-28. SCAT normalized longitudinal acceleration: helicopter and tilt rotor, 4,000 ft, 95°F.

(3) Longitudinal deceleration. Figures N-V-29 through N-V-32 present the longitudinal deceleration of the five preliminary design concepts, normalized to the helicopter. A review of the data shows the compound ABC and compound helicopter to have substantially better deceleration characteristics over the complete speed band, followed by the ABC, helicopter, and TR, respectively. Deceleration is similar to acceleration relative to survivability potential in that the greater the capability the greater the inherent potential for survivability given that deceleration is the tactic of the moment. The advantage of the compound ABC and compound helicopter is prominent at the higher end of the speed band where deceleration is an essential performance characteristic relative to masking to evade threat systems. On the basis of this data, the preferred systems would be the compound ABC and the compound helicopter, followed by the ABC, helicopter, and TR, respectively.

(4) Turn rate agility. Figures N-V-33 through N-V-36 present the turn rate agility of the five preliminary design concepts, normalized to the helicopter. The data shows the helicopter to clearly be the preferred system from 0-120 kt. However, beyond 100 kt the helicopter becomes the least preferred. Above 100 kt, the preferred system is the TR, followed by the compound helicopter, compound ABC, ABC, and helicopter.

(5) Turn radius maneuver. Figures N-V-37 through N-V-40 present the turn radius agility of the five preliminary design concepts, normalized to the helicopter. Partioning the speed band into three intervals shows that in the 0-40 kts interval, the order of preference is helicopter, compound helicopter/ABC, compound ABC, and TR. In the +40-120 kt region, the preferred system would remain the helicopter, followed by the compound helicopter, ABC, compound ABC, then the TR. Above 120 kt, the order would be TR, compound helicopter, compound ABC, and helicopter.

(6) Climb maneuver. Figures N-V-41 through N-V-44 present normalized data for rate of climb. The data indicates that the order of preference would be TR, compound helicopter, then helicopter, ABC, and compound ABC in the 0-40 kt interval. In the +40-120 kt interval, the ordering would change to compound helicopter, compound ABC, helicopter/ABC, then TR. Above 120 kt, the ordering would be TR, compound helicopter/compound ABC, then helicopter/ABC.

(7) Specific excess power. Specific excess power (Ps) is a measure of the relative capability of different designs to change energy state as related to air combat maneuvers. In air combat, the maneuvering advantage will go to the aircraft that can enter an engagement at a higher energy level and maintain more energy than his opponent, or enters the engagement at a lower energy level but can gain energy quicker than his opponent. The energy level is expressed by an aircraft's capability to change altitude relative to time (dhe/dt). This definition is synonomous with rate of climb and for first order approach, comparison of the data presented above can be used to indicate which aircraft have the advantage. A review of the speed-power polars for each aircraft shows the helicopters to be grouped in the 80-110 kt interval for which Ps would be maximized and that the TR is maximized in the 130-150 kt interval. The selection as to which speed band is more desirable would be based on the specific mission being carried out and is left to the LHX-COEA for resolution.

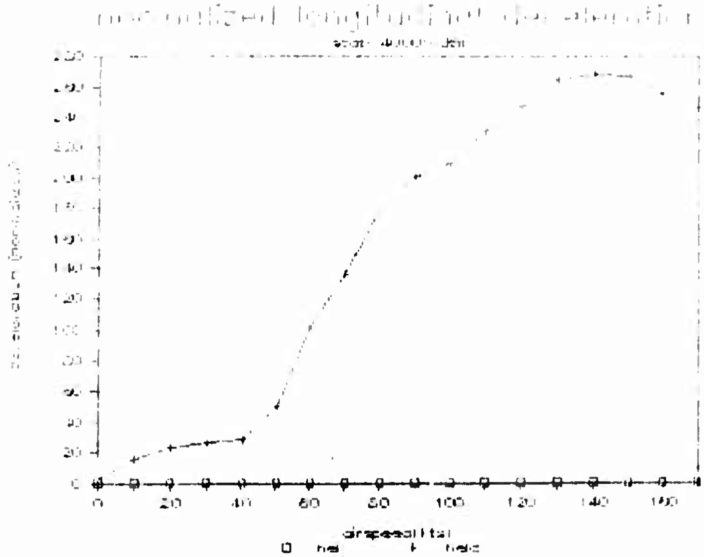

Figure N-V-29. SCAT normalized longitudinal deceleration: helicopter and helicopter-compound, 4,000 ft, 95°F.

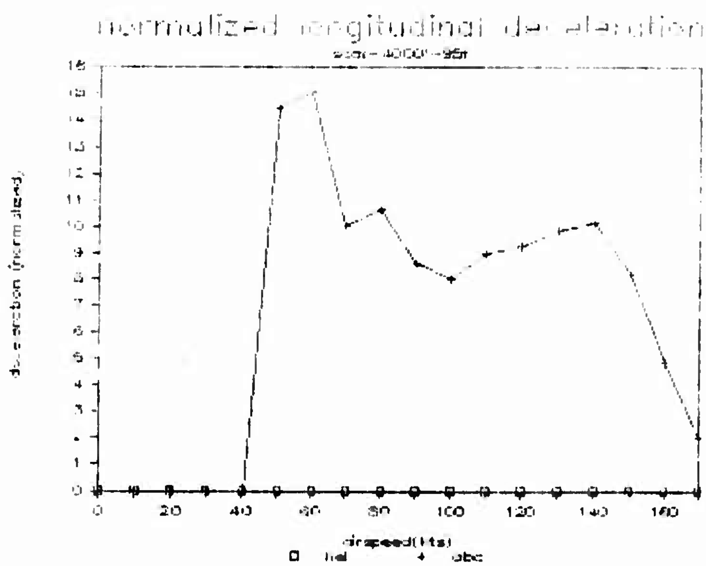

Figure N-V-30. SCAT normalized longitudinal deceleration: helicopter and ABC, 4,000 ft, 95°F.

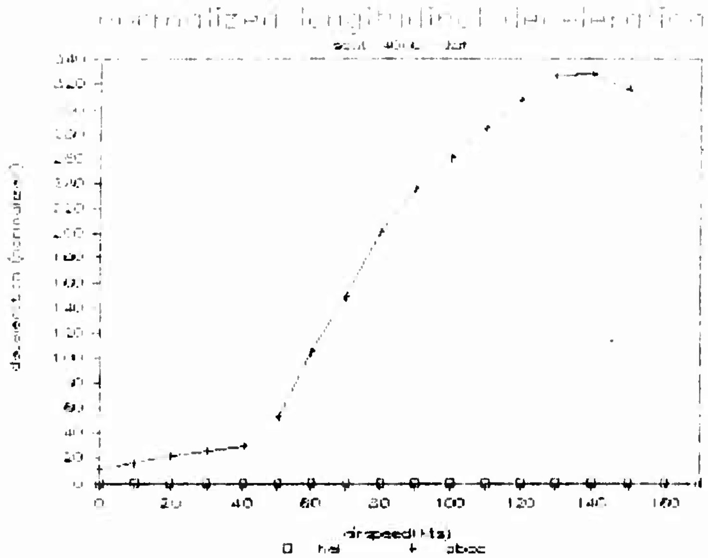

Figure N-V-31. SCAT normalized longitudinal deceleration: helicopter and ABC-compound, 4,000 ft, 95°F.

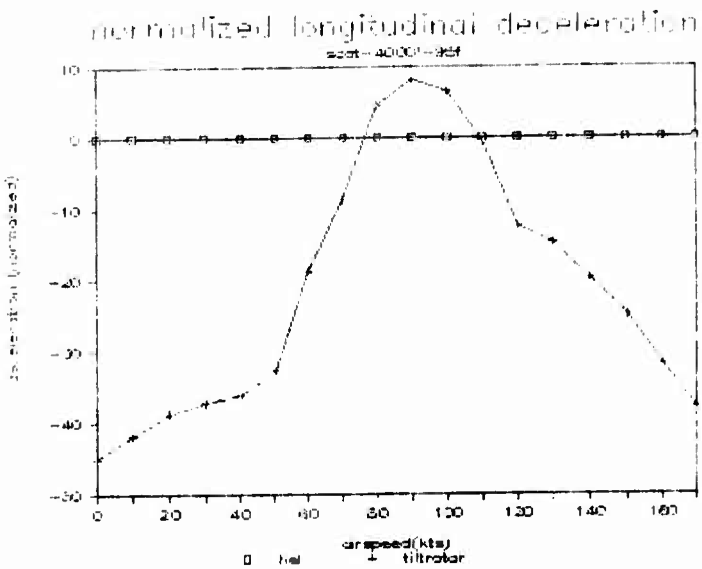

Figure N-V-32. SCAT normalized longitudinal deceleration: helicopter and tilt rotor, 4,000 ft, 95°F.

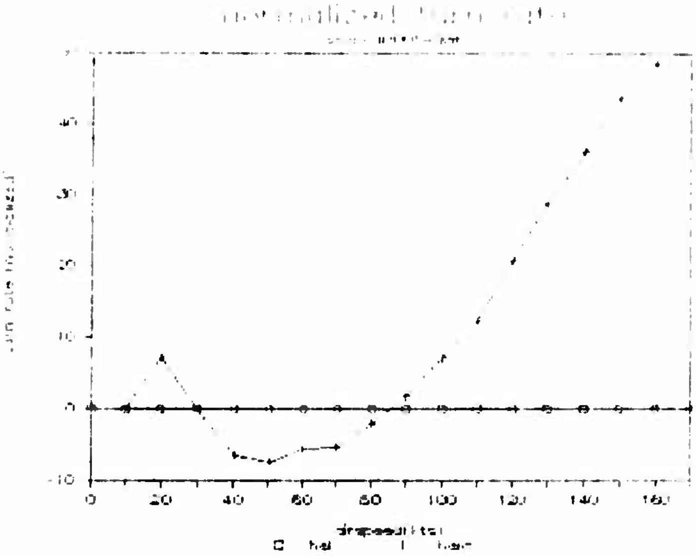

Figure N-V-33. SCAT normalized turn rate: helicopter and helicopter-compound, 4,000 ft, 95°F.

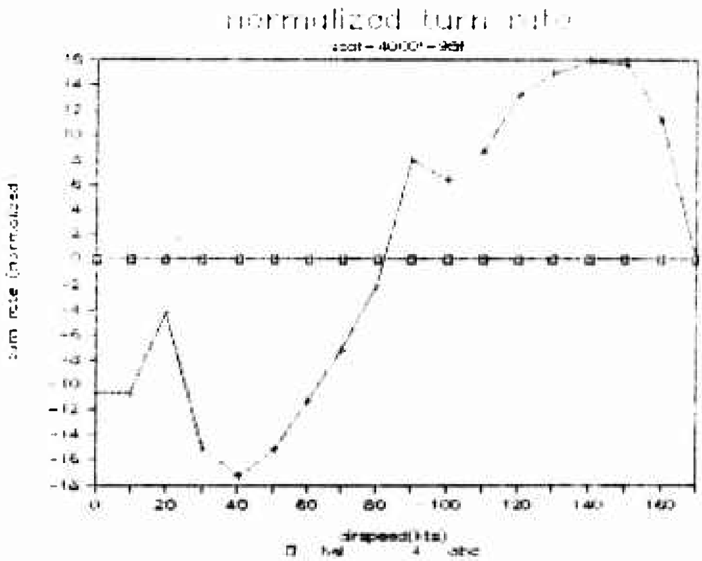

Figure N-V-34. SCAT normalized turn rate: helicopter and ABC, 4,000 ft, 95°F.

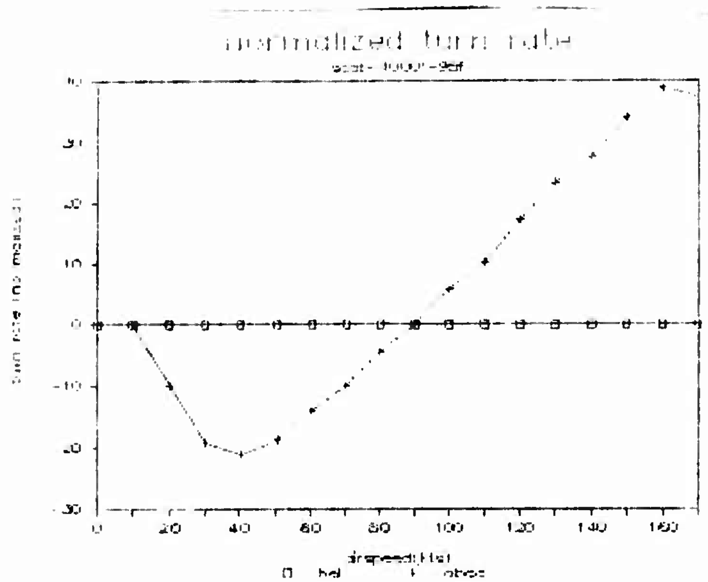

Figure N-V-35. SCAT normalized turn rate: helicopter and ABC-compound, 4,000 ft, 95°F.

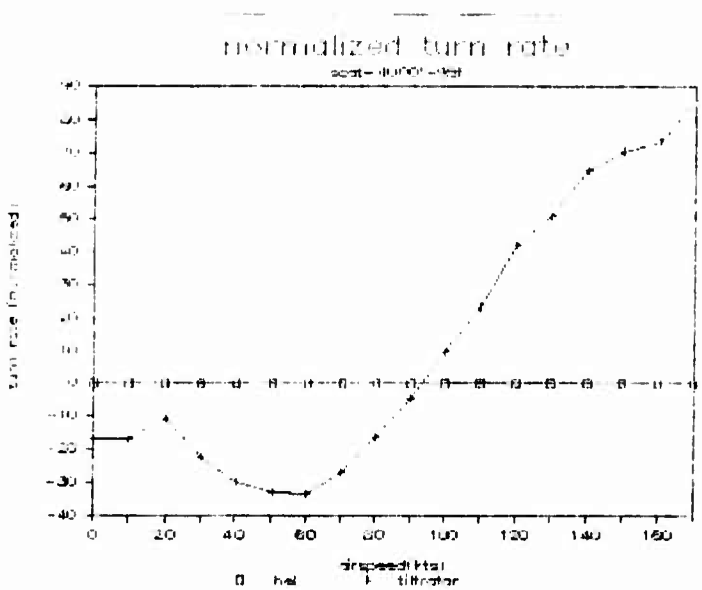

Figure N-V-36. SCAT normalized turn rate: helicopter and tilt rotor, 4,000 ft, 95°F.

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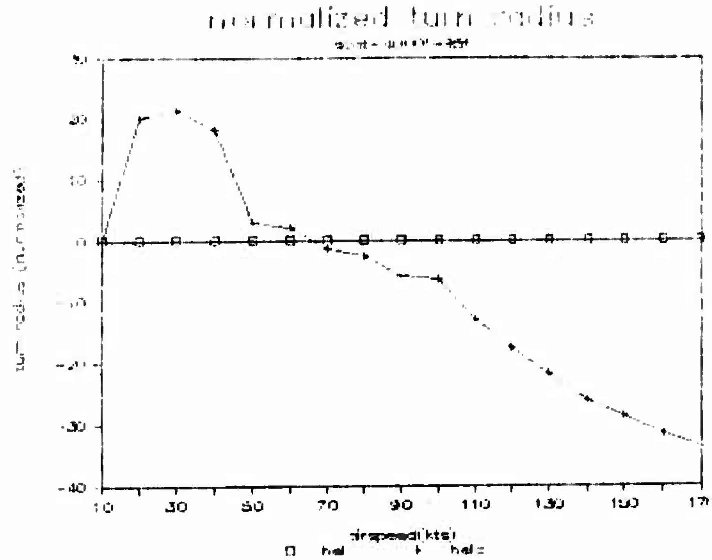

Figure N-V-37. SCAT normalized turn radius: helicopter and helicopter-compound, 4,000 ft, 95°F.

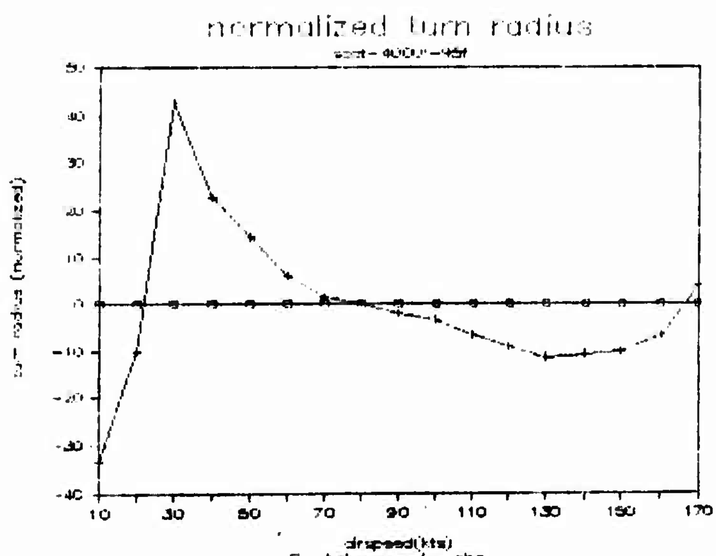

Figure N-V-38. SCAT normalized turn radius: helicopter and ABC, 4,000 ft, 95°F.

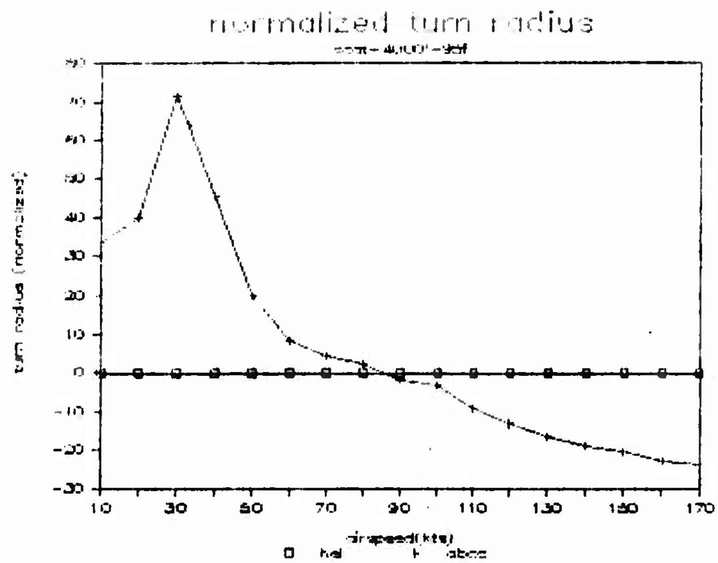

Figure N-V-39. SCAT normalized turn radius: helicopter and ABC-compound, 4,000 ft, 95°F.

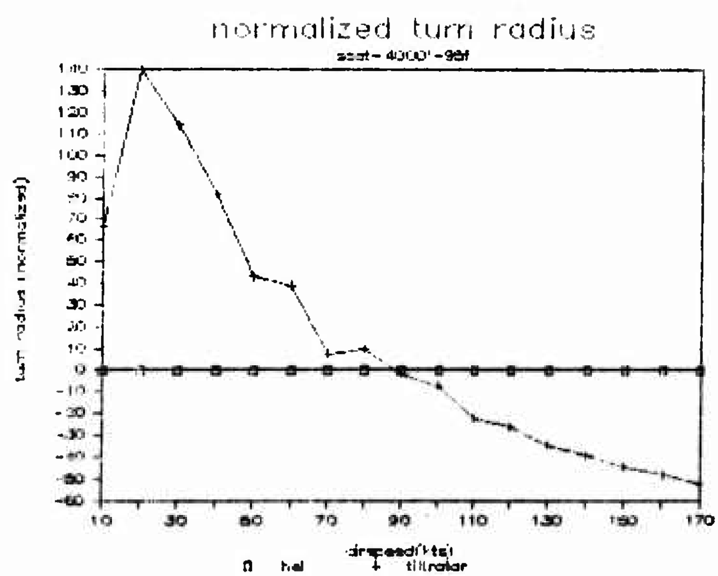

Figure N-V-40. SCAT normalized turn radius: helicopter and tilt rotor, 4,000 ft, 95°F.

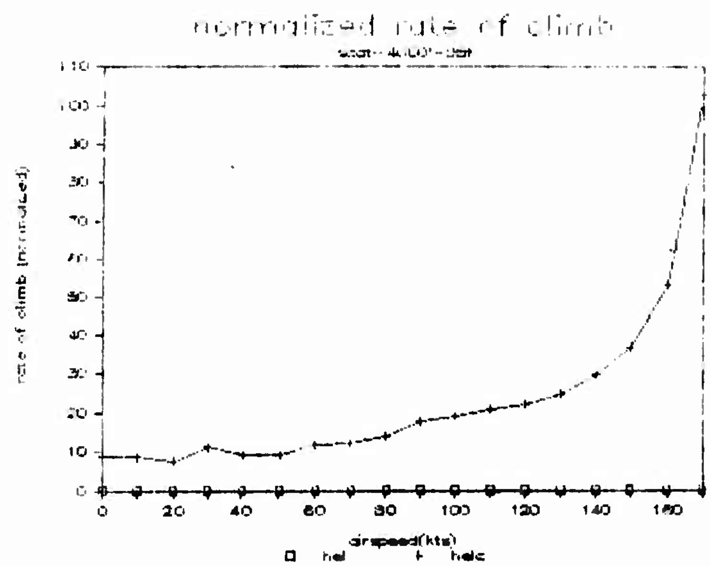

Figure N-V-41. SCAT normalized climb rate: helicopter and helicopter-compound, 4,000 ft, 95°F.

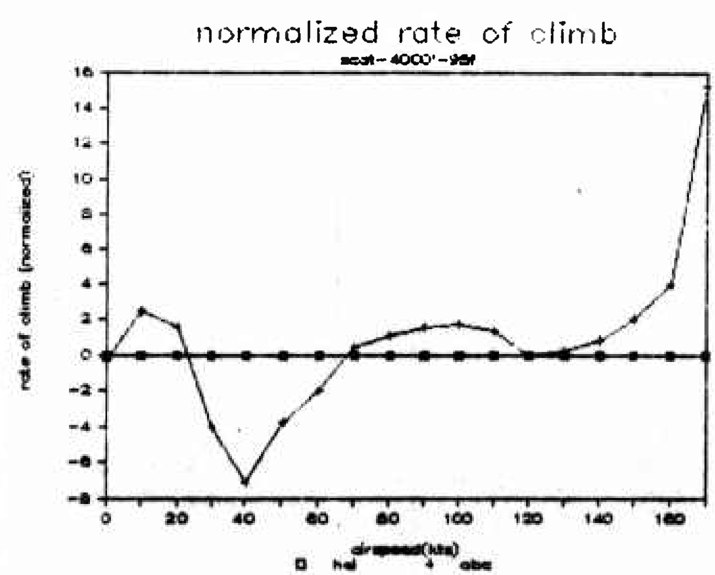

Figure N-V-42. SCAT normalized climb rate: helicopter and ABC, 4,000 ft, 95°F.

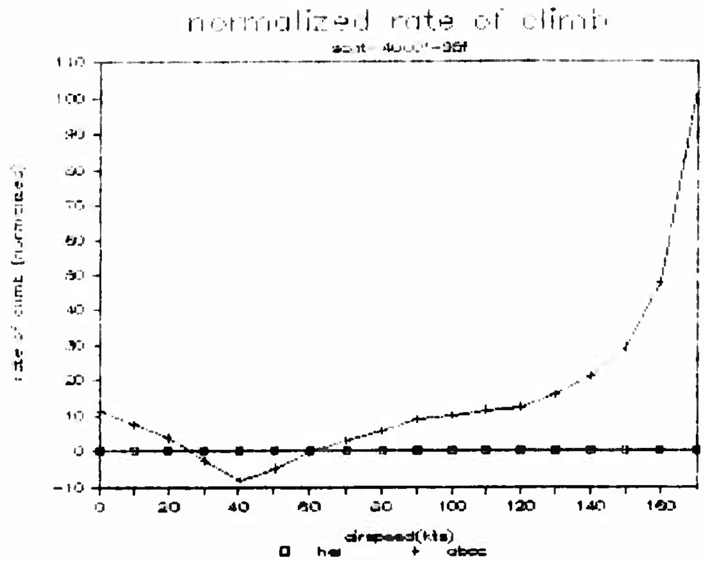

Figure N-V-43. SCAT normalized climb rate: helicopter and ABC-compound, 4,000 ft, 95°F.

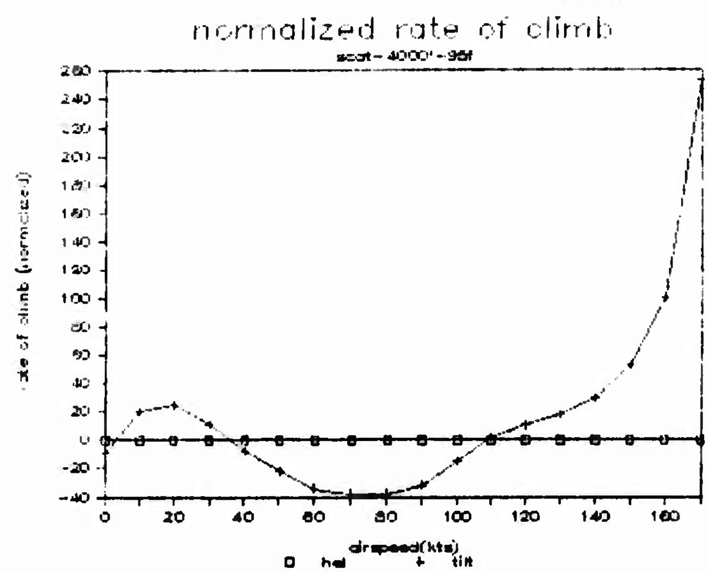

Figure N-V-44. SCAT normalized climb rate: helicopter and tilt rotor, 4,000 ft, 95°F.

(8) Rate of descent maneuver. Figures N-V-45 through N-V-48 present normalized data for descent. High rates of descent are not necessarily desirable within the altitude band in which the LHX will be operating because of obvious reasons. However, the ability to descend in a controlled, rapid manner is essential in minimizing the threat. The comparisons presented are based on the "best attainable" and ignores operating altitude. On this basis, the data shows that the 0-40 kt ranking would be compound helicopter, ABC, compound ABC, and TR, followed by the helicopter. In the +40-120 kt region, the ranking is the same. However, above 120 kt, the ordering changes to TR, ABC, compound ABC, helicopter, and compound helicopter.

(9) Ranking. In order to determine a preferred system, a number ranking technique is used to establish (if possible) the preferred system in each speed interval previously discussed. Since there are five designs, values of 1 through 5 are used with the low values being the preferred value. However, if two aircraft are essentially equal, the two values are added, divided by 2, and the results given to each configuration. The results are tabulated in figure N-V-49. From figure N-V-49, it is noted that the helicopter and compound helicopter are the preferred systems for the first two speed intervals and that the TR is the preferred system above 120 kt.

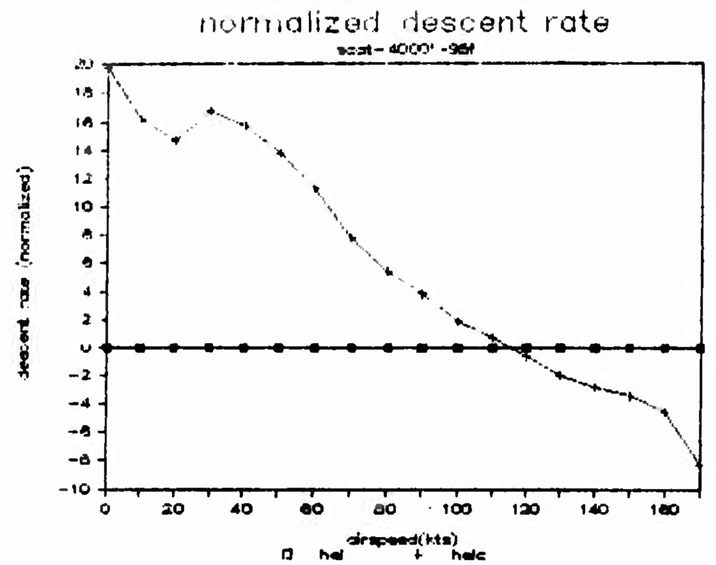

Figure N-V-45. SCAT normalized descent rate: helicopter and helicopter-compound, 4,000 ft, 95°F.

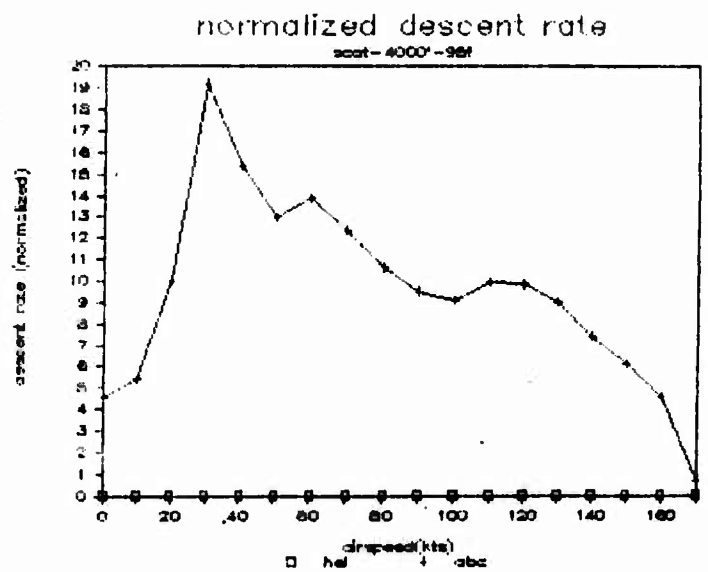

Figure N-V-46. SCAT normalized descent rate: helicopter and ABC, 4,000 ft, 95°F.

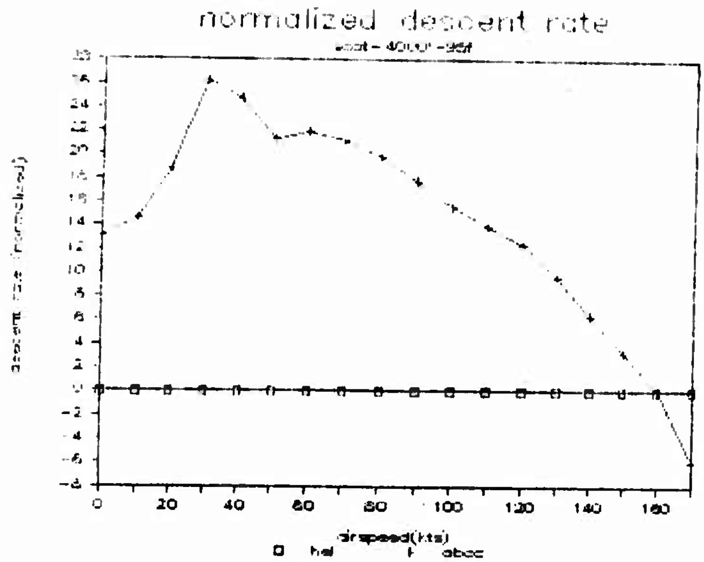

Figure N-V-47. SCAT normalized descent rate: helicopter and ABC-compound, 4,000 ft, 95°F.

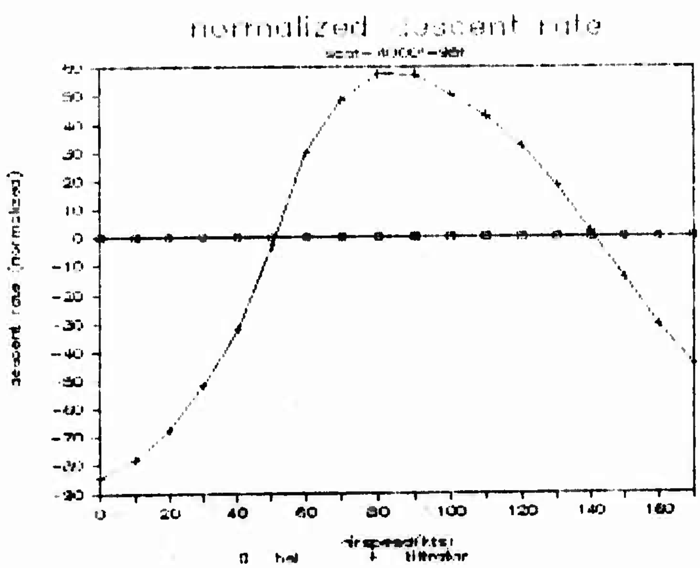

Figure N-V-48. SCAT normalized descent rate: helicopter and tilt rotor, 4,000 ft, 95°F.

	0-40 Kt					+40-120 Kt					Above 120 Kt				
	HEL*	HEL-C*	ABC	ABC-C*	TR	HEL	HEL-C	ABC	ABC-C	TR	HEL	HEL-C	ABC	ABC-C	TR
Long Acceleration	1	4	2	4	4	2	4.5	3	4.5	1	3.5	5.0	3.5	2	1
Long Deceleration	2.5	1.5	2.5	1.5	5	4	2	3	1.0	5.0	4	2	3	1	5
Turn Rate	1	3.5	3.5	3.5	3.5	1	3.5	3.5	3.5	3.5	5	2	4	3	1
Turn Radius	1	2.5	2.5	4	5	1	3	3	3	5	4.5	2.5	4.5	3	1
Climb Rate	4	2	4	4	1	3.5	1	3.5	2	5	4.5	2.5	4.5	2.5	1
Descent	5	1	3	3	3	5	1	3	3	3	4	5	2.5	2.5	1
Raw Score	4.5	14.5	17.5	20.0	21.5	16.5	15	19	17	22.5	26	18.5	21.5	14	10
Normalized to Helicopter	1.0	1.0	.83	.73	.67	1.0	1.10	.87	.97	.73	1.0	1.41	1.21	1.86	2.60

*HEL - helicopter
HEL-C - compound helicopter
ABC-C - compound ABC

Figure N-V-49. M/A scores of LHX-SCAT candidates, 4,000'/95°F.

(10) Maneuverability/agility - quality index. In a further effort to identify a clearly preferred system, a M/A quality index is offered which uses the scores from figure N-V-49. In addition, the unit cost and design gross weight are presented for each speed interval for each candidate. This technique is outlined below:

$$\text{M/A Quality Index} = \frac{\text{PD HEL}}{\text{PD X}} \times \frac{\text{Cost HEL}}{\text{Cost X}} \times \frac{\text{Weight (Wt) HEL}}{\text{Wt X}}$$

where: PD HEL = Ranking score of preliminary design helicopter (figure N-V-49)

PD X = Ranking score of preliminary design of other rotorcraft (figure N-V-49)

Cost HEL = Unit cost ($M) of PD helicopter (per 1,000 units)

Cost X = Unit cost ($M) of other PD rotorcraft (per 1,000 units)

Wt HEL = Helicopter design gross weight

Wt X = Rotorcraft design gross weight

PD HEL M/A quality index = 1.00

Index values >1.00 indicate system is preferred relative to helicopter

Results obtained using this technique are listed in figure N-V-50.

	0-40 Kt	+40-120 Kt	Above 120 Kt
Helicopter	*1.00	*1.00	1.00
Compound Helicopter	.81	.89	1.14
ABC	.68	.716	0.996
Compound ABC	.525	.703	1.345
TR	.516	.561	*1.989

*Best value within the given speed range.

Figure N-V-50. M/A quality index, LHX-SCAT, 4,000'/95°F.

The filtration analysis to this point shows the helicopter to be the preferred system up to 120 kt. Above 120 kt, the ranking is TR, compound ABC, compound helicopter, helicopter, and ABC. However, because of the TR high index value, it would be the only preferred system. At this point in the analysis another aspect needs to be introduced in order to identify a "preferred" system. The additional consideration is the amount of time that speed (low/high) is utilized based on mission profiles. The percentage of time per mission that the rotorcraft would be operating above 100 kt is shown in figure N-V-51. Percentages are based on flying the missions with the helicopter. From figure N-V-51, it is observed that 9 of the 12 missions (75 percent) have flight segments that result in the rotorcraft flying above 100 kt for 65 percent, or greater, of the total mission time. This analysis concludes that although a majority of the SCAT missions in the Middle East (and Europe) are flown in excess of 100 kt, the critical part of the mission is that portion where the rotorcraft must operate at low speed in and out of confined areas and where M/A is prerequisite to mission success; therefore, the helicopter is the overall (speed/range) preferred system.

Mission	Mission Definition	Percent Time V > 100 Knots
12	Antiarmor	66.7
13	Antipersonnel/materiel	84.3
14	Special operations forces (SOF) strike	95.7
15	Reconnaissance	58.8
16	Security	24.8
17	Deep strike	87.4
18	Rear area combat operations	66.7
19	Suppression of enemy air defense (SEAD)	65.0
20	Amphibious assault	78.1
25	Air-to-air	65
26	Offensive air	65
45	Nuclear, biological, and chemical (NBC) survey	27.9

Figure N-V-51. SCAT helicopter; percent time above 100 kt, Middle East, 4,000'/95°F.

b. Utility Designs (4,000 ft/95°F). The M/A characteristics of the Utility designs at 4,000 ft/95°F are presented in figures N-V-52 through N-V-69. Comparisons of these data in a normalized format are presented in figures N-V-70 through N-V-99. As in section a, the data have been normalized to the helicopter. In comparison to SCAT missions which require moderate time at NOE operation at battle positions from 15 to 60 minutes, the Utility will operate predominantly at best range speed, followed by best endurance speed. At first glance it would seem logical to place more emphasis on the relative M/A parameters in this speed interval. However, from a handling qualities/capabilities standpoint, the low speed qualities are equally important because of terminal area maneuvers due to space/obstacles, etc. In the following analysis, the three speed intervals used in the previous section are retained, i.e., 0-40 kt for NOE, +40-120 kt (contour), and above 120 kt (low level).

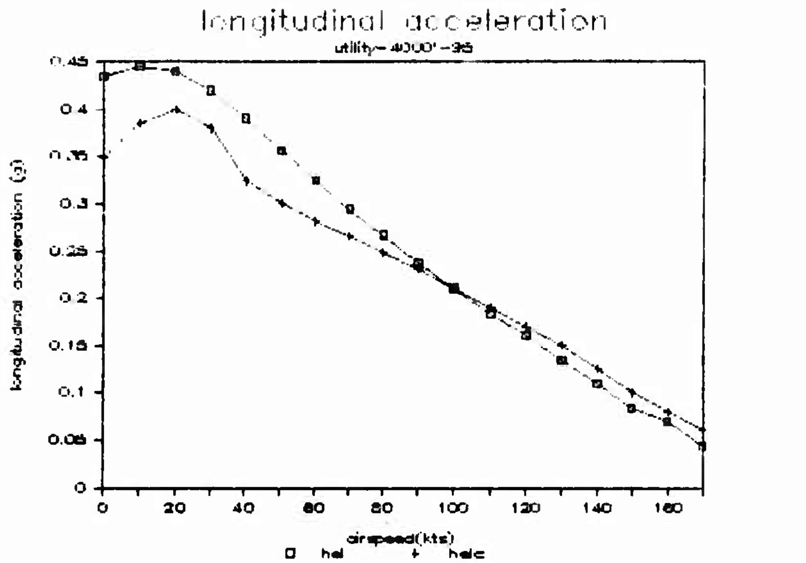

Figure N-V-52. Utility longitudinal acceleration: helicopter and helicopter-compound, 4,000 ft, 95°F.

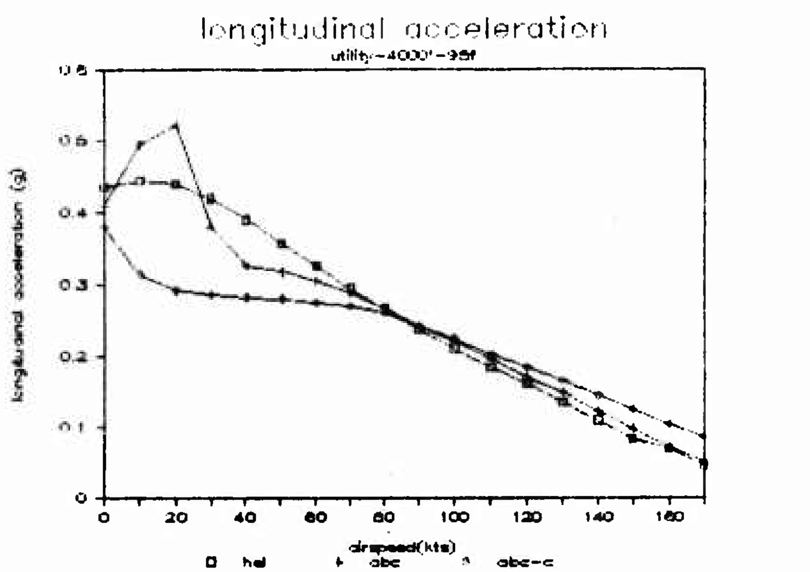

Figure N-V-53. Utility longitudinal acceleration: helicopter, ABC, and ABC-compound, 4,000 ft, 95°F.

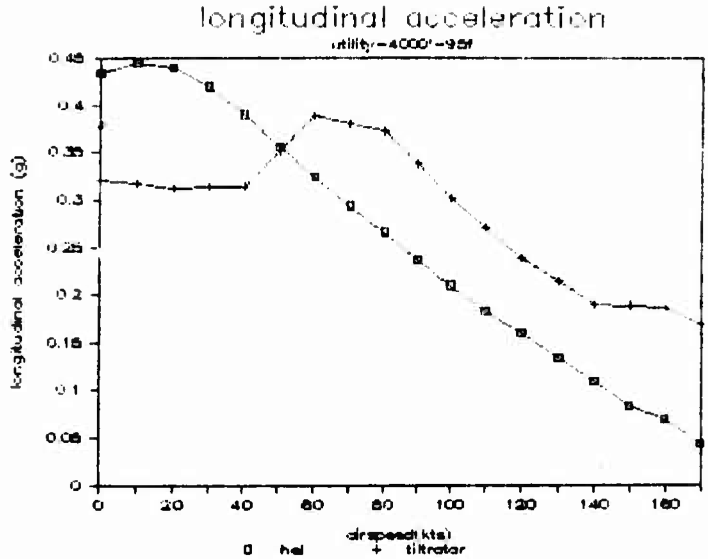

Figure N-V-54. Utility longitudinal acceleration: helicopter and tilt rotor, 4,000 ft, 95°F.

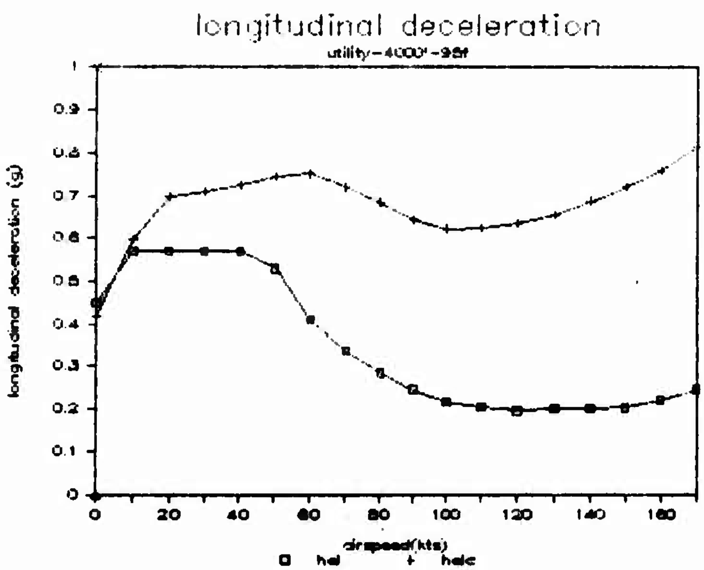

Figure N-V-55. Utility longitudinal deceleration: helicopter and helicopter-compound, 4,000 ft, 95°F.

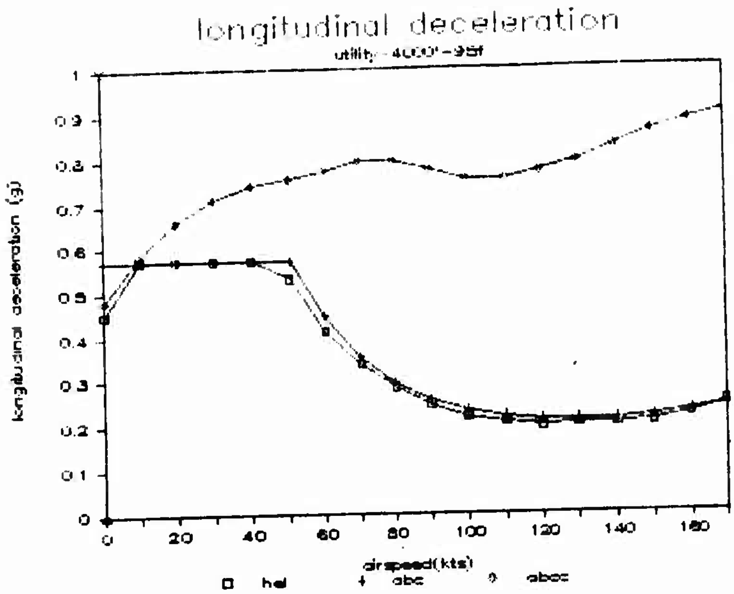

Figure N-V-56. Utility longitudinal deceleration: helicopter, ABC, and ABC-compound, 4,000 ft, 95°F.

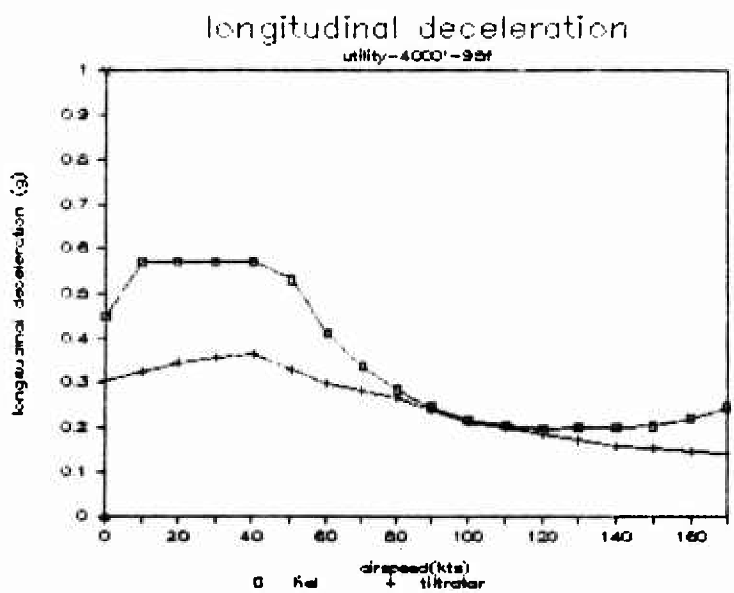

Figure N-V-57. Utility longitudinal deceleration: helicopter and tilt rotor, 4,000 ft, 95°F.

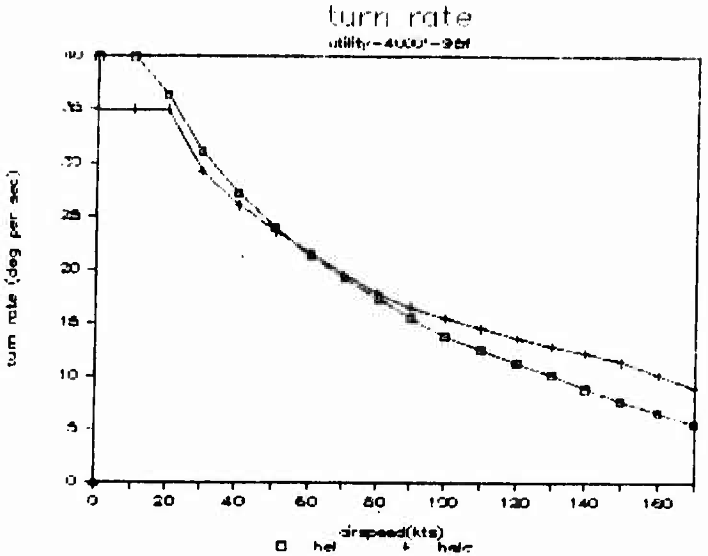

Figure N-V-58. Utility turn rate: helicopter and helicopter-compound, 4,000 ft, 95°F.

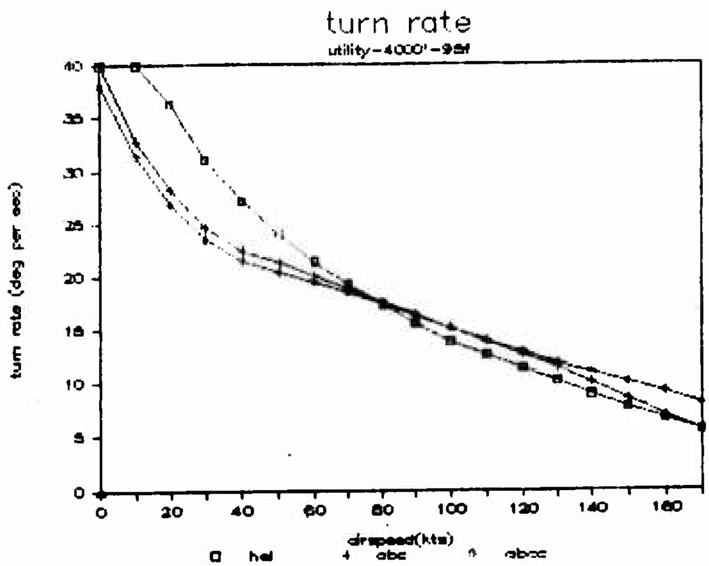

Figure N-V-59. Utility turn rate: helicopter, ABC, and ABC-compound, 4,000 ft, 95°F.

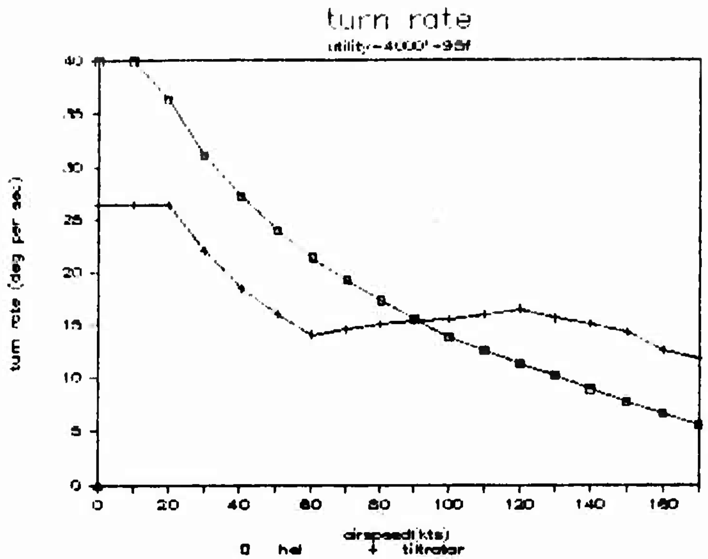

Figure N-V-60. Utility turn rate: helicopter and tilt rotor, 4,000 ft, 95°F.

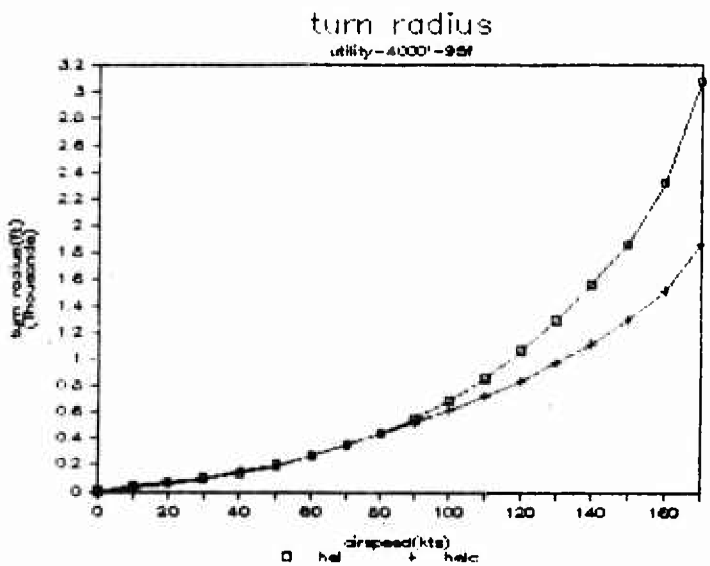

Figure N-V-61. Utility turn radius: helicopter and helicopter-compound, 4,000 ft, 95°F.

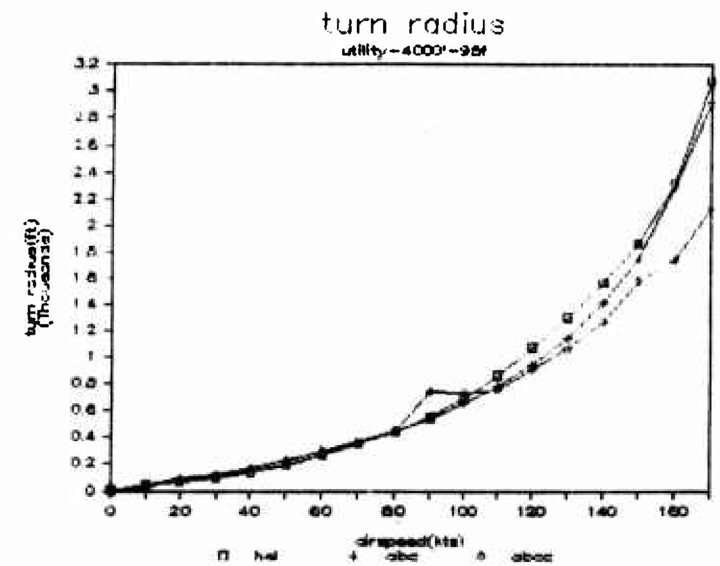

Figure N-V-62. Utility turn radius: helicopter, ABC, and ABC-compound, 4,000 ft, 95°F.

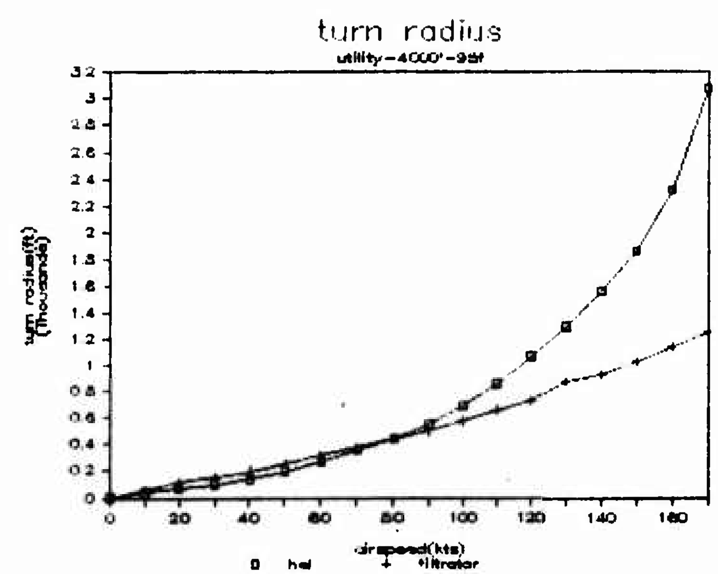

Figure N-V-63. Utility turn radius: helicopter and tilt rotor, 4,000 ft, 95°F.

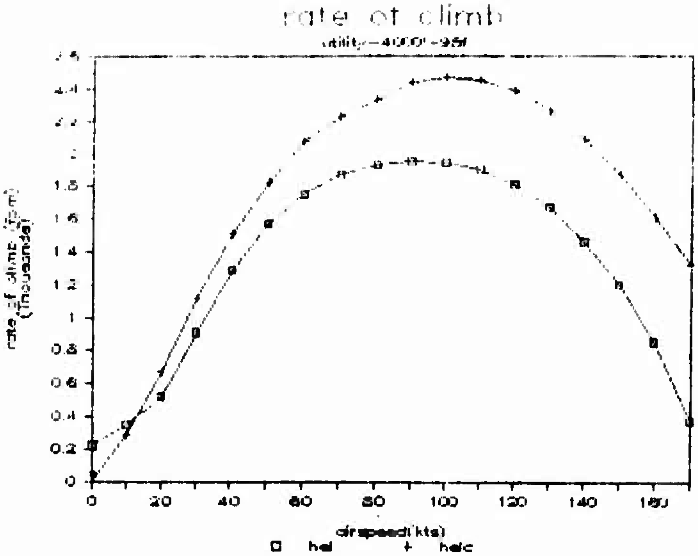

Figure N-V-64. Utility climb rate: helicopter and helicopter-compound, 4,000 ft, 95°F.

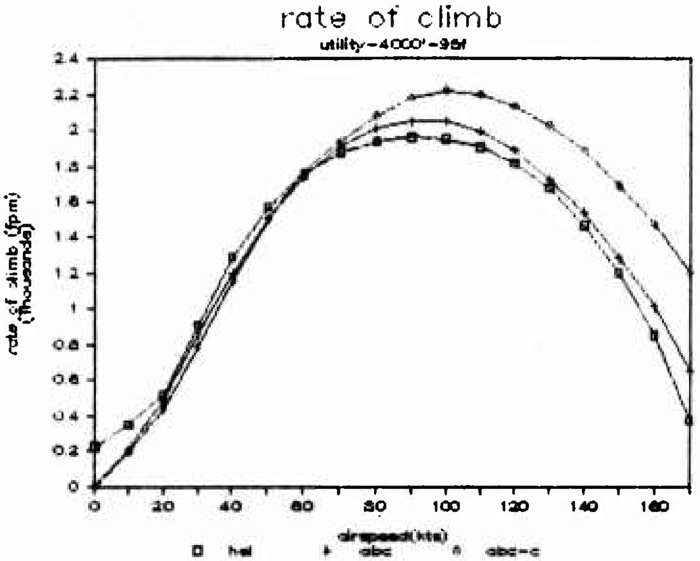

Figure N-V-65. Utility climb rate: helicopter, ABC, and ABC-compound, 4,000 ft, 95°F.

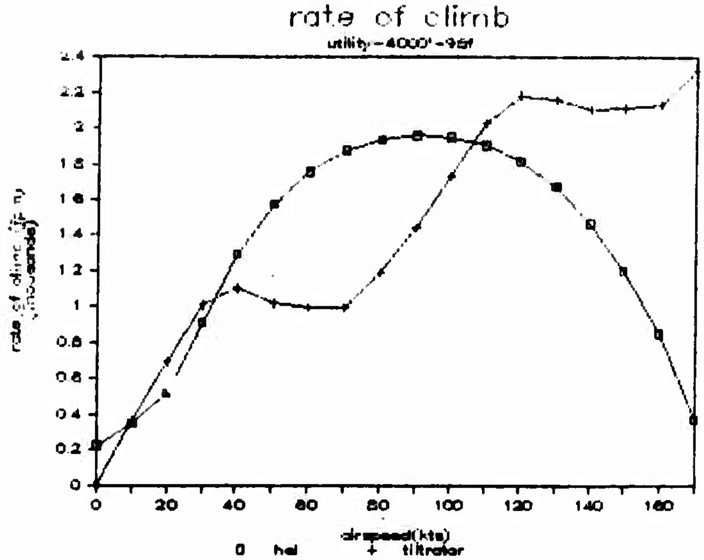

Figure N-V-66. Utility climb rate: helicopter and tilt rotor, 4,000 ft, 95°F.

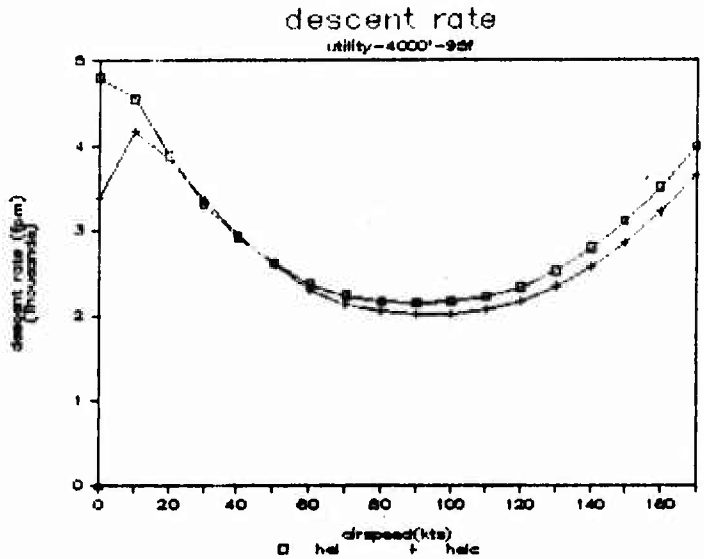

Figure N-V-67. Utility descent rate: helicopter and helicopter-compound, 4,000 ft, 95°F.

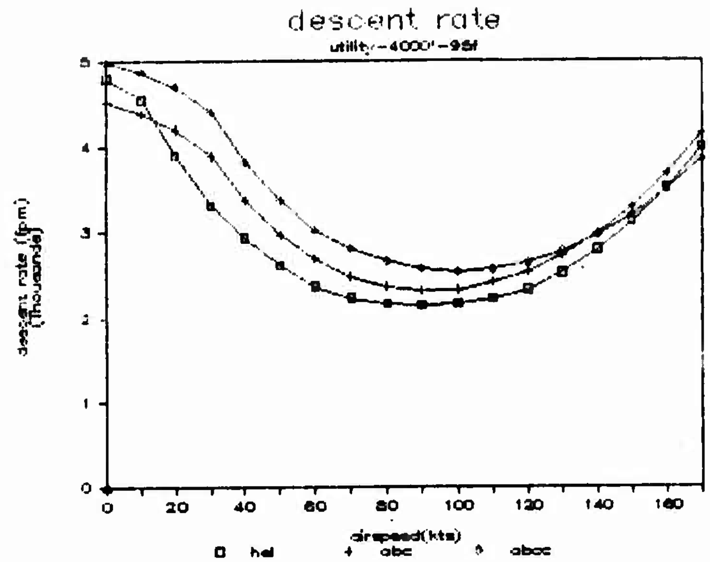

Figure N-V-68. Utility descent rate: helicopter, ABC, and ABC-compound, 4,000 ft, 95°F.

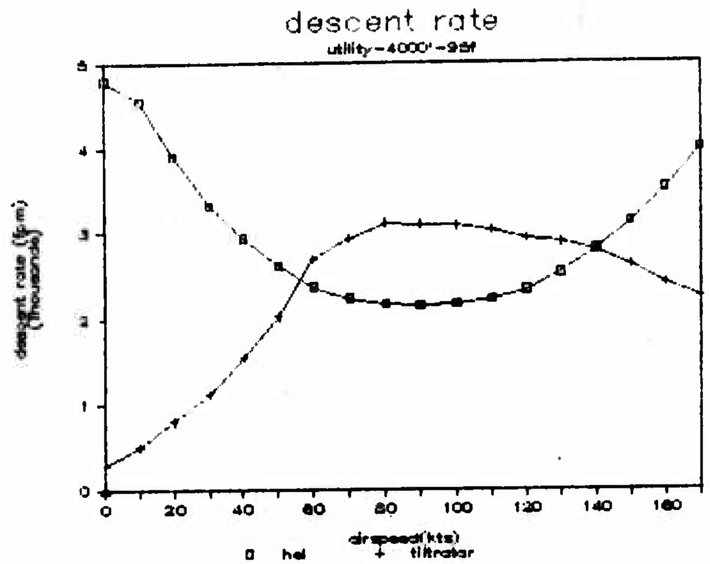

Figure N-V-69. Utility descent rate: helicopter and tilt rotor, 4,000 ft, 95°F.

(1) Longitudinal acceleration. Figures N-V-70 through N-V-73 depict the relative comparison of the five Utility designs. Inspection of the data shows that for the NOE region, the helicopter would be preferred followed by the other designs being approximately equal. In the low speed interval (40-120 kt), the TR would be preferred followed by the other designs. Further, the cruise interval (>120 kt) indicates the order of preference to be TR, compound ABC, compound helicopter, ABC, and helicopter. Figure N-V-74 presents relative preference using the ranking technique developed in the previous section. As stated in the previous section, a low score is best. Where designs were essentially equal their position values were summed, then averaged. The results of figure N-V-74 indicate essentially the same findings from the SCAT investigations which are: the low speed or NOE regime favors the helicopter, while at the other end, i.e., cruise, the TR is the more favorable system.

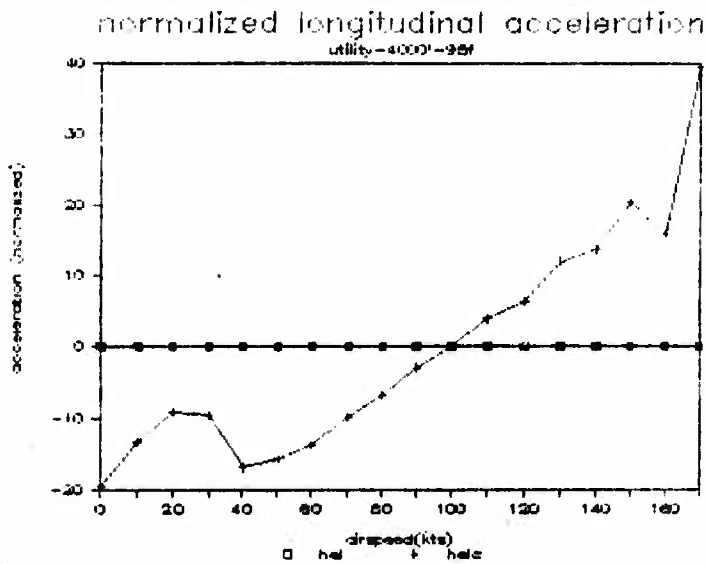

Figure N-V-70. Utility normalized longitudinal acceleration: helicopter and helicopter-compound, 4,000 ft, 95°F.

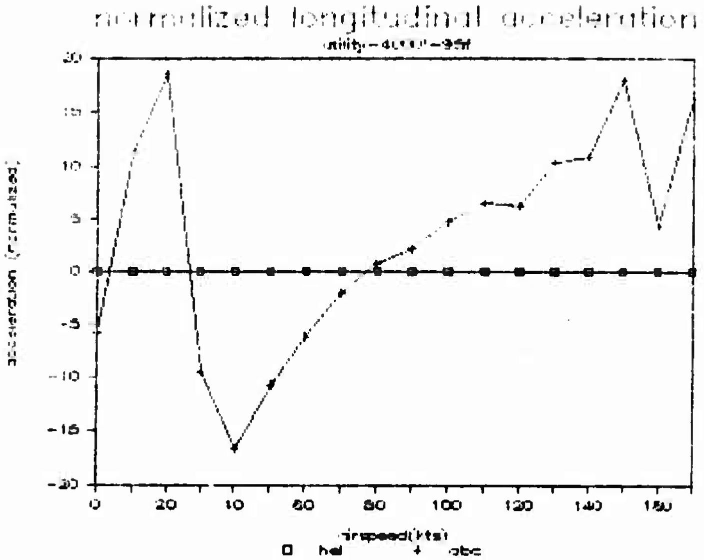

Figure N-V-71. **Utility normalized longitudinal acceleration: helicopter and ABC, 4,000 ft, 95°F.**

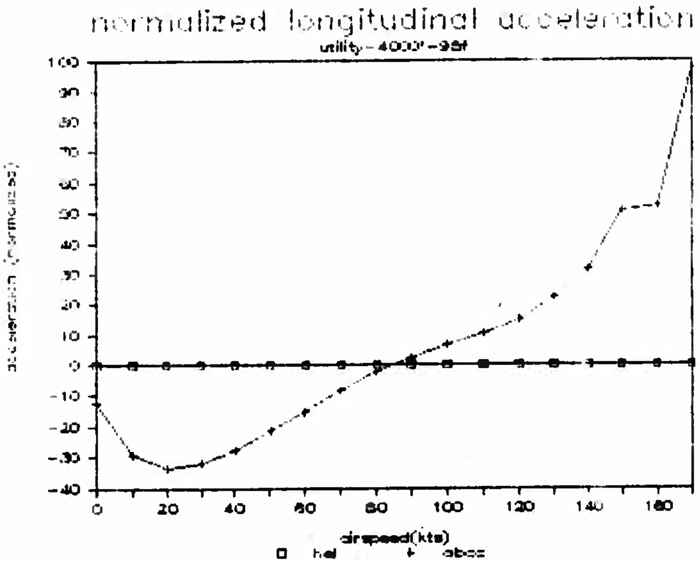

Figure N-V-72. Utility normalized longitudinal acceleration: helicopter and ABC-compound, 4,000 ft, 95°F.

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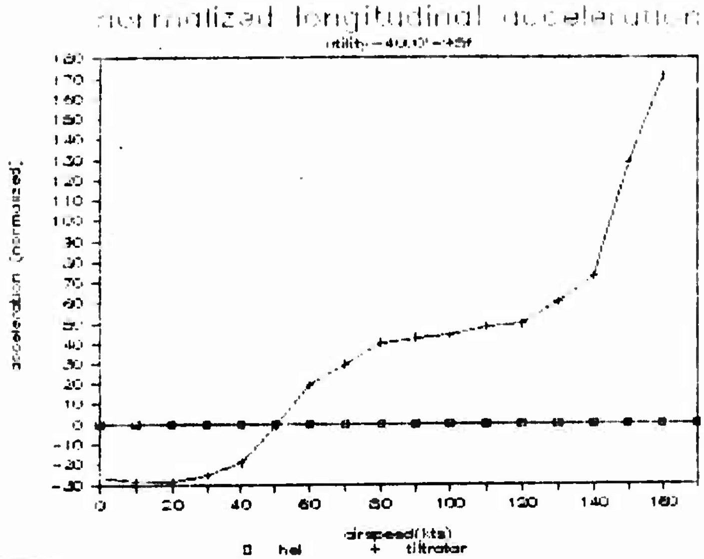

Figure N-V-73. Utility normalized longitudinal acceleration: helicopter and tilt rotor, 4,000 ft, 95°F.

	Helicopter	Compound Helicopter	ABC	Compound ABC	TR
NOE	1	3.5	3.5	3.5	3.5
Low Speed	3.5	3.5	3.5	3.5	1
Cruise	5	3.5	3.5	2	1
Total Score	9.5	10.5	10.5	9.0	5.5

Figure N-V-74. Longitudinal acceleration/utility, 4,000 ft/95°F.

(2) Longitudinal deceleration. Figures N-V-76 through N-V-79 present the deceleration characteristics of the five Utility designs. Inspection of the data shows two of the compounds to be an order of magnitude better than the other three configurations as initially observed for the SCAT. The primary reason for this is the thrusting prop which can be used to establish the deceleration. Breaking the designs into the three categories results in figure N-V-75. From figure N-V-75, it appears that the best balanced system from the perspective of deceleration is the compound ABC, followed closely by the compound helicopter. The other three designs are orders of magnitude away.

	Helicopter	Compound Helicopter	ABC	Compound ABC	TR
NOE	3.5	1.5	3.5	1.5	5.0
Low Speed	3.5	2.0	3.5	1.0	5
Cruise	3.5	2.0	3.5	1.0	5
Total Score	10.5	5.5	10.5	3.5	15.0

Figure N-V-75. Longitudinal deceleration/utility 4,000 ft/95°F.

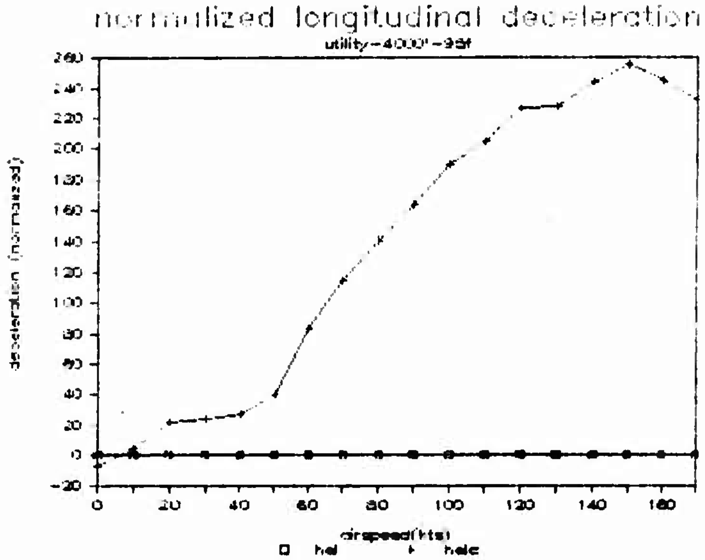

Figure N-V-76. Utility normalized longitudinal deceleration: helicopter and helicopter-compound, 4,000 ft, 95°F.

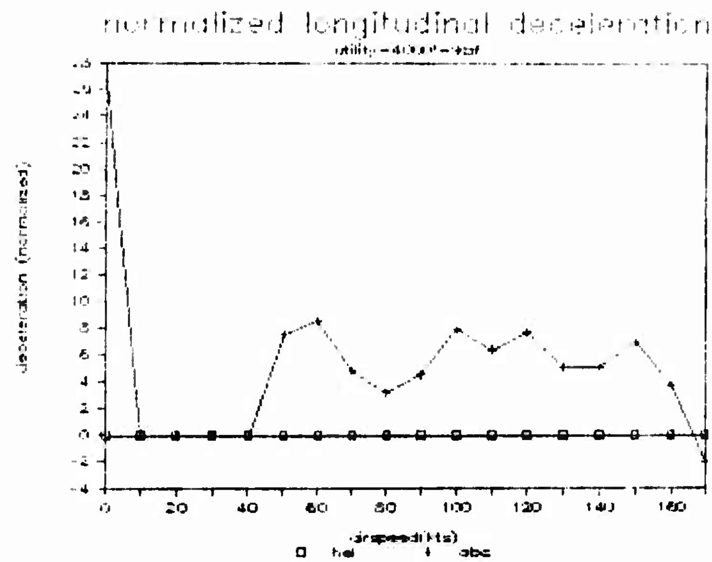

Figure N-V-77. Utility normalized longitudinal deceleration: helicopter and ABC, 4,000 ft, 95°F.

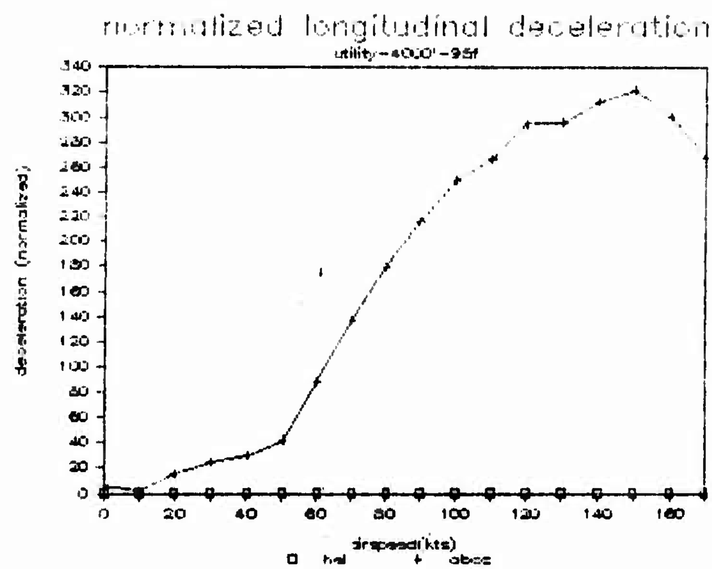

Figure N-V-78. Utility normalized longitudinal deceleration: helicopter and ABC-compound, 4,000 ft, 95°F.

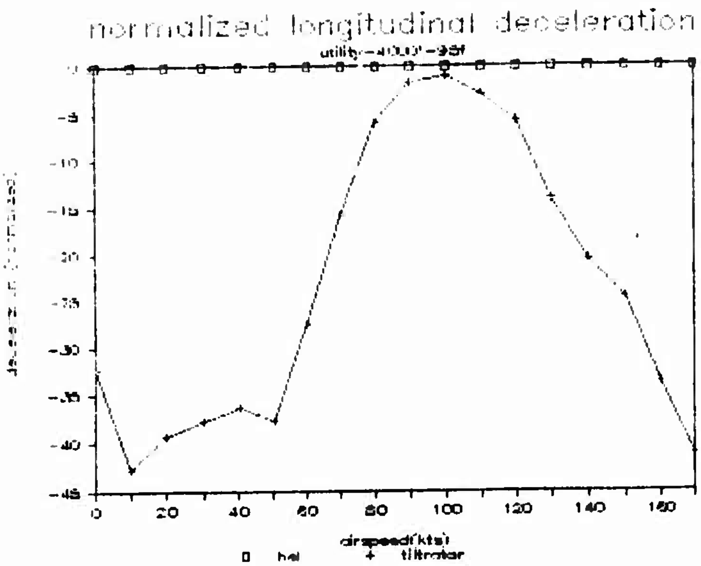

Figure N-V-79. Utility normalized longitudinal deceleration: helicopter and tilt rotor, 4,000 ft, 95°F.

(3) Turn rate agility. Figures N-V-81 through N-V-84 graphically illustrate the relative (normalized) turn rate capabilities of each Utility design. Figure N-V-80 reflects an attempt to assign a numerical significance to each design. The data presented in figure N-V-80 indicate the compound helicopter to be the better system, followed by the helicopter, TR, compound ABC, and the ABC, respectively.

	Helicopter	Compound Helicopter	ABC	Compound ABC	TR
NOE	1.0	2.0	3.5	3.5	5.0
Low Speed	3.0	3.0	3.0	3.0	3.0
Cruise	4.5	2.0	4.5	3.0	1.0
Total Score	8.5	7.0	11.0	9.5	9.0

Figure N-V-80. Turn rate agility/utility, 4,000 ft/95°F.

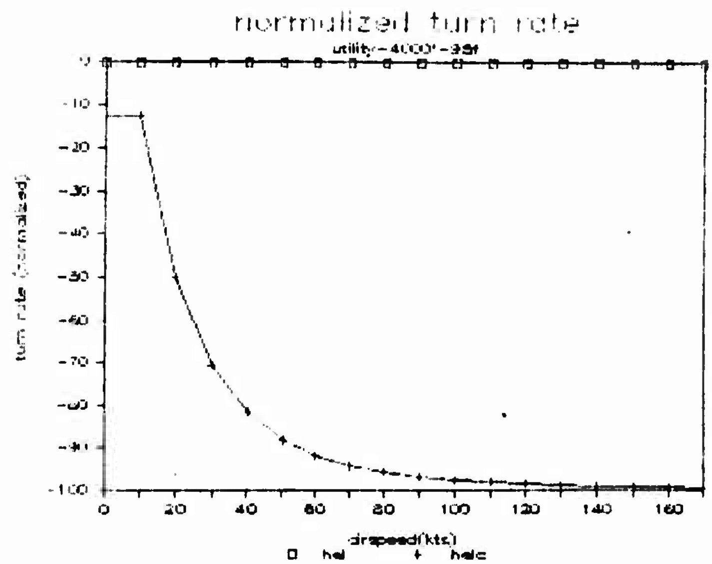

Figure N-V-81. Utility normalized turn rate: helicopter and helicopter-compound, 4,000 ft, 95°F.

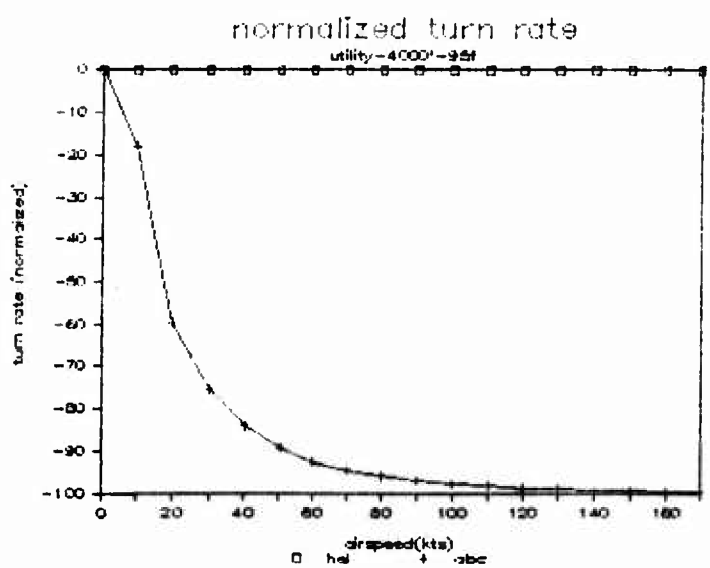

Figure N-V-82. Utility normalized turn rate: helicopter and ABC, 4,000 ft, 95°F.

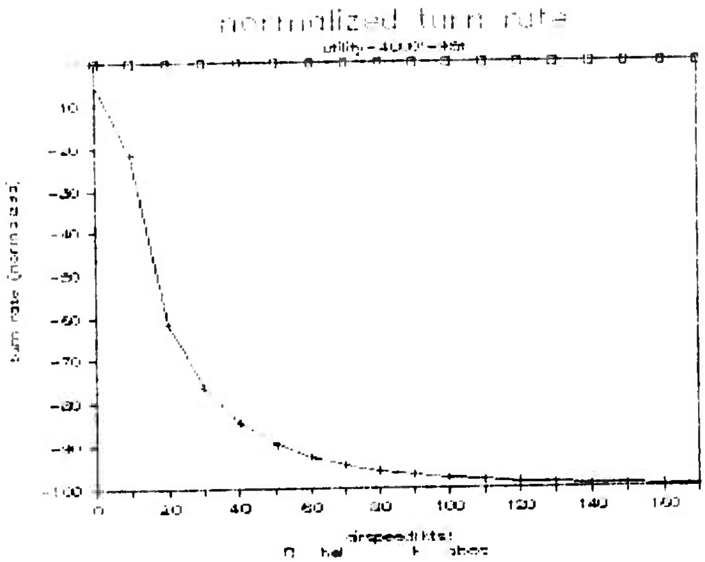

Figure N-V-83. Utility normalized turn rate: helicopter and ABC-compound, 4,000 ft, 95°F.

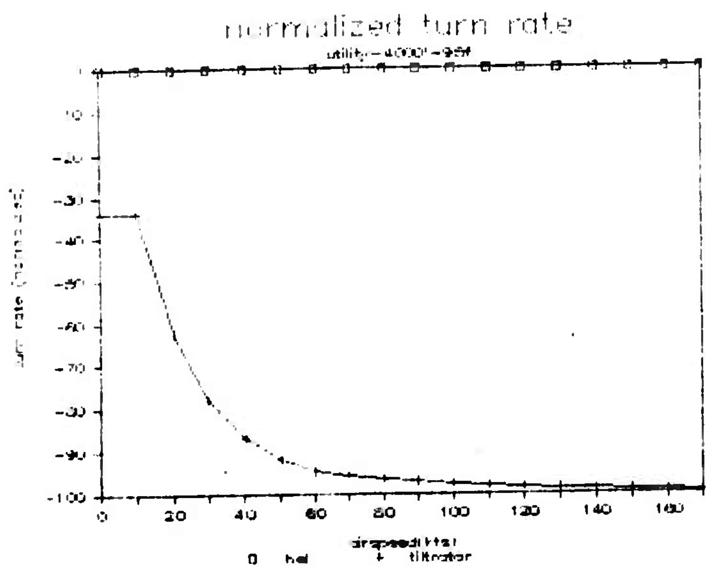

Figure N-V-84. Utility normalized turn rate: helicopter and tilt rotor, 4,000 ft, 95°F.

(4) **Turn radius capability.** As shown in figures N-V-86 through N-V-89, the turn radius is reflective of the turn rate and because it is, the results would be the same as found for the turn radius. Therefore, a table replicating figure N-V-85 is appropriate.

	Helicopter	Compound Helicopter	ABC	Compound ABC	TR
NOE	1.0	2.0	3.5	3.5	5.0
Low Speed	3.0	3.0	3.0	3.0	3.0
Cruise	4.5	2.0	4.5	3.0	1.0
Total Score	8.5	7.0	11.0	9.5	9.0

Figure N-V-85. Turn radius/utility, 4,000 ft/95°F.

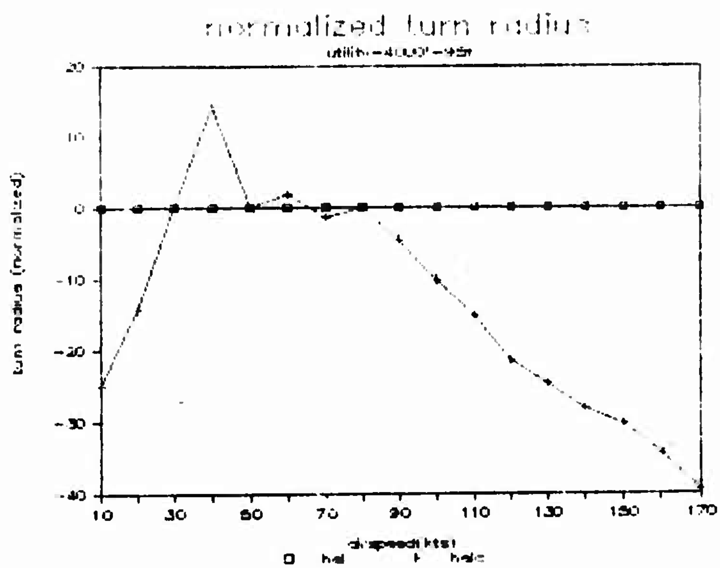

Figure N-V-86. Utility normalized turn radius: helicopter and helicopter-compound, 4,000 ft, 95°F.

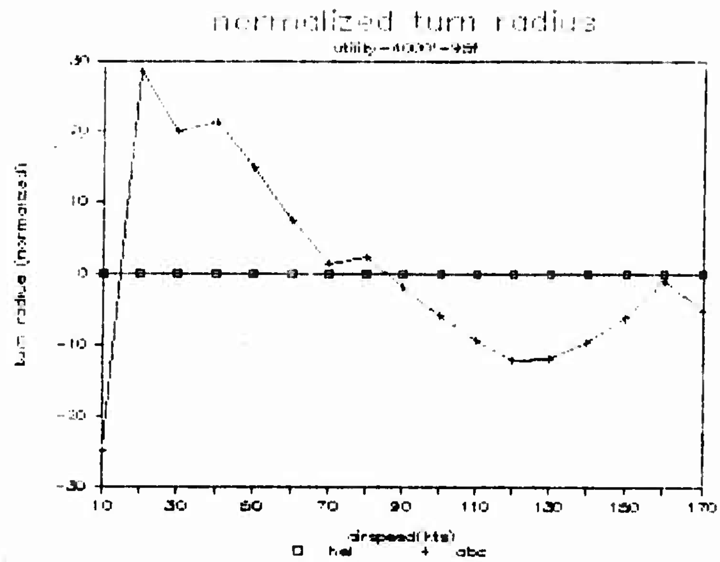

Figure N-V-87. Utility normalized turn radius: helicopter and ABC, 4,000 ft, 95°F.

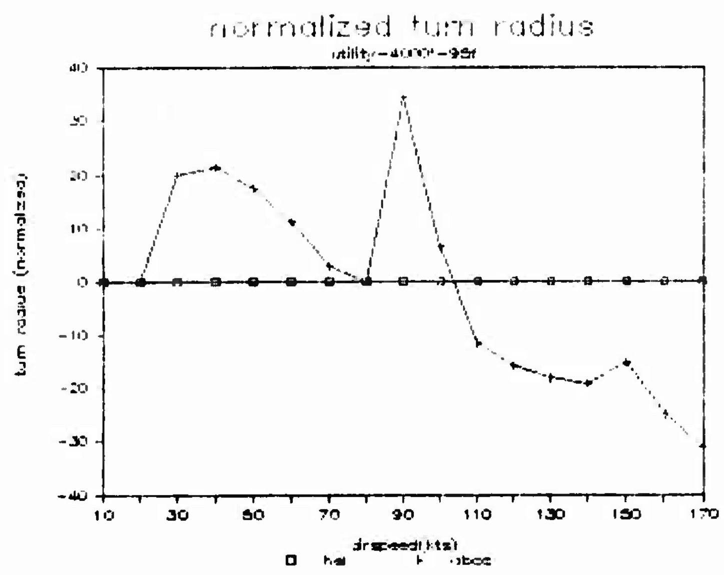

Figure N-V-88. Utility normalized turn radius: helicopter and ABC-compound, 4,000 ft, 95°F.

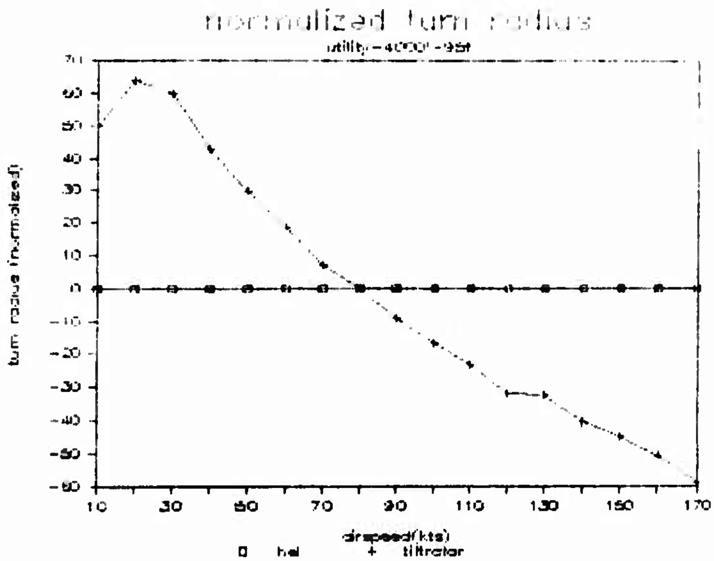

Figure N-V-89. Utility normalized turn radius: helicopter and tilt rotor, 4,000 ft, 95°F.

(5) Rate of climb. The relative climb characteristics as a function of forward speed are presented in figures N-V-91 through N-V-94. Assigning relative scores to each results in figure N-V-90. From figure N-V-90, it is noted that the compound helicopter is the design with a more balanced capability.

	Helicopter	Compound Helicopter	ABC	Compound ABC	TR
NOE	1	3.5	3.5	3.5	3.5
Low Speed	3.0	1.0	3.0	3.0	5.0
Cruise	4.5	2.0	4.5	3.0	1.0
Total Score	8.5	6.5	11.0	9.5	9.5

Figure N-V-90. Rate of climb/utility, 4,000 ft/95°F.

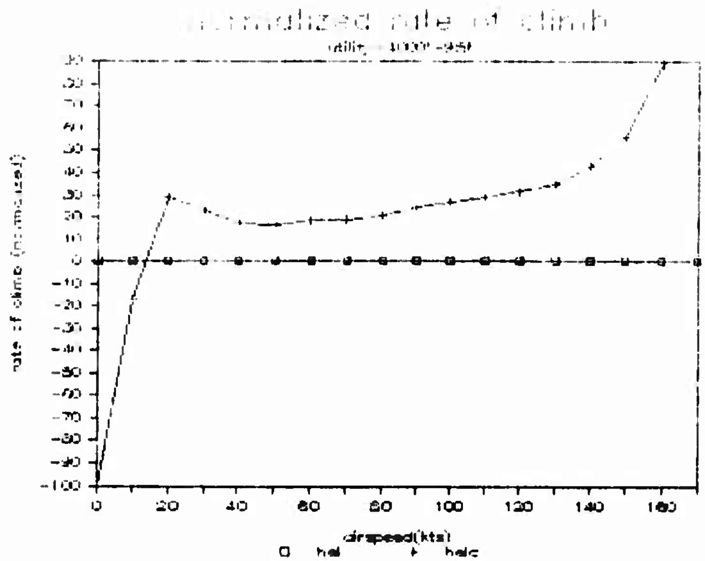

Figure N-V-91. **Utility normalized climb rate: helicopter and helicopter-compound, 4,000 ft, 95°F.**

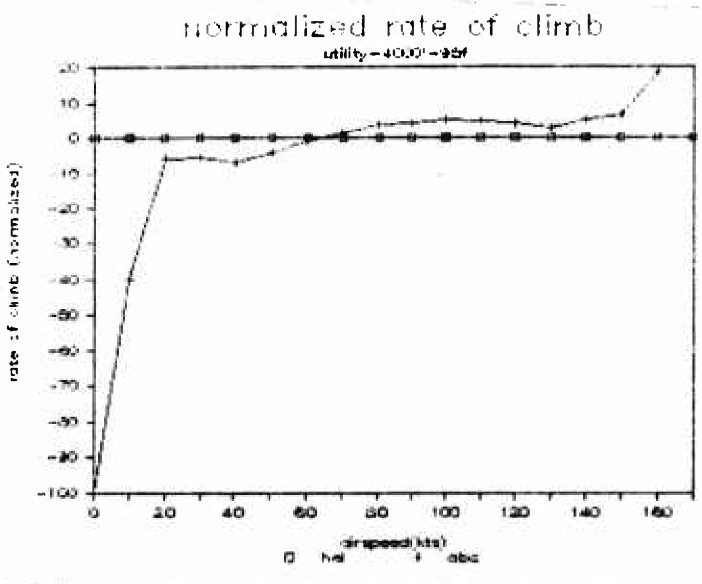

Figure N-V-92. **Utility normalized climb rate: helicopter and ABC, 4,000 ft, 95°F.**

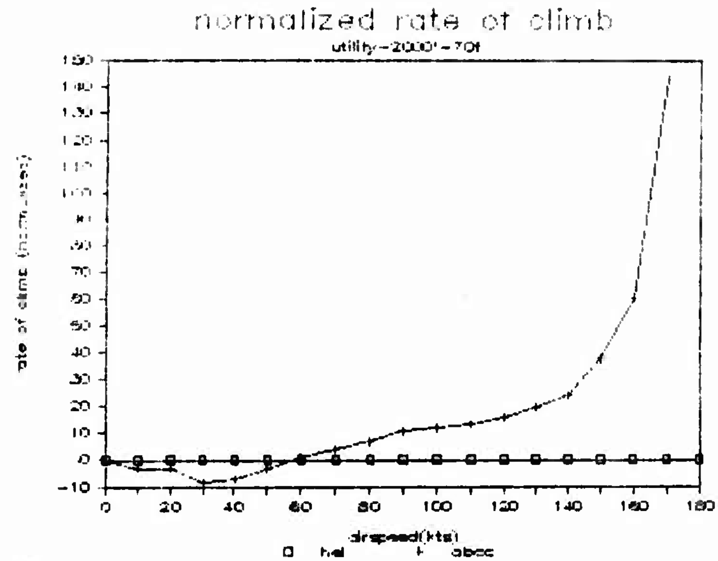

Figure N-V-93. Utility normalized climb rate: helicopter and ABC-compound, 4,000 ft, 95°F.

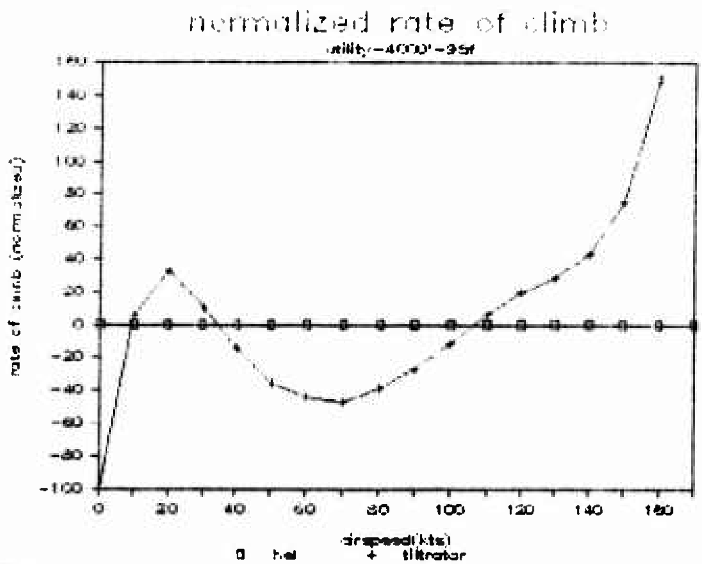

Figure N-V-94. Utility normalized climb rate: helicopter and tilt rotor, 4,000 ft, 95°F.

(6) Rate of descent maneuver. Figures N-V-96 through N-V-99 depict the normalized rate of descent characteristics for the Utility designs. Partitioning the data into the three categories as previously done results in figure N-V-95. From figure N-V-95, it is noted that the compound ABC design has a lower score than the other designs.

	Helicopter	Compound Helicopter	ABC	Compound ABC	TR
NOE	5.0	1.0	3.5	2.0	3.5
Low Speed	4.0	5.0	3.0	1.0	2.0
Cruise	4.0	5.0	2.5	2.5	1.0
Total Score	13.0	11.0	9.0	5.5	6.5

Figure N-V-95. Rate of descent/utility, 4,000 ft/95°F.

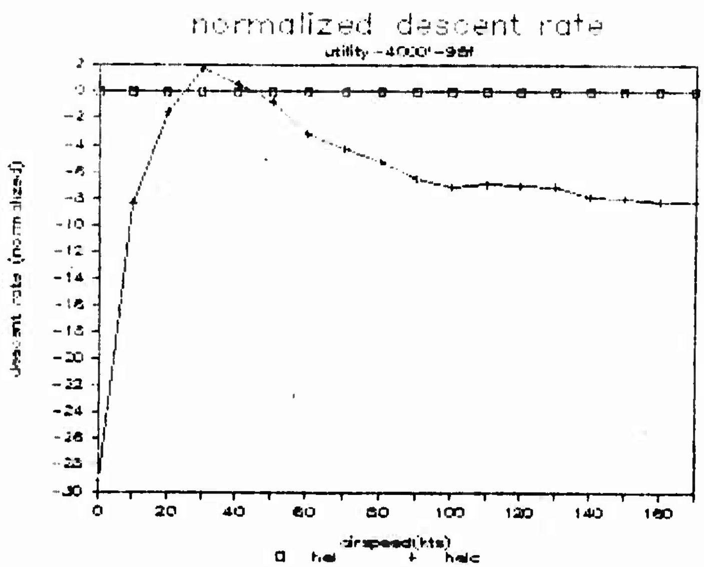

Figure N-V-96. Utility normalized descent rate: helicopter and helicopter-compound, 4,000 ft, 95°F.

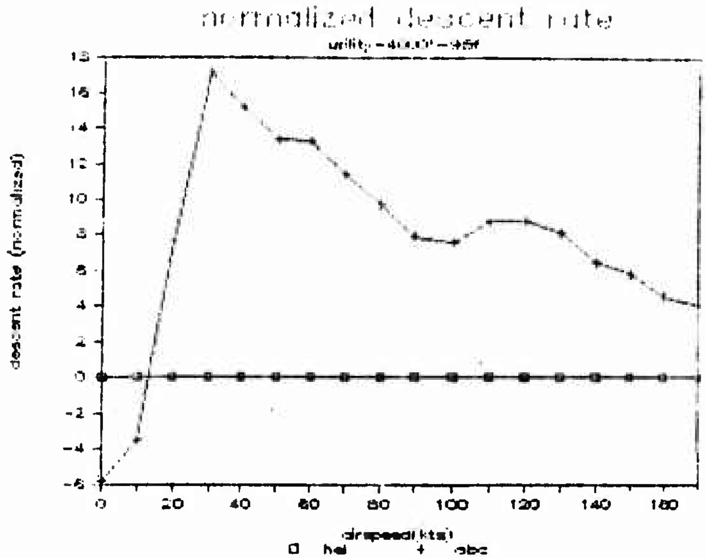

Figure N-V-97. Utility normalized descent rate: helicopter and ABC, 4,000 ft, 95°F.

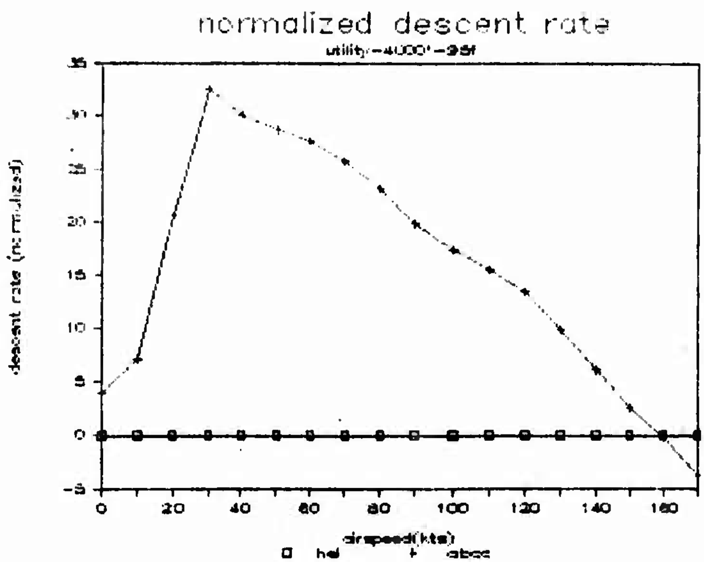

Figure N-V-98. Utility normalised descent rate: helicopter and ABC-compound, 4,000 ft, 95°F.

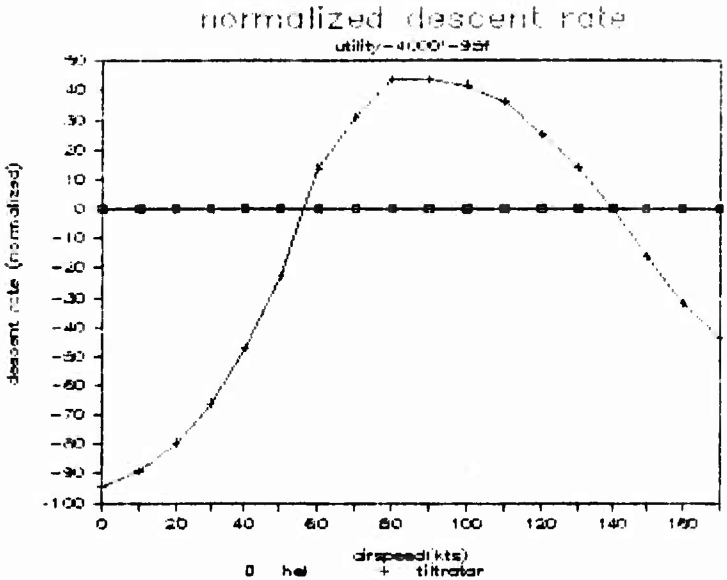

Figure N-V-99. Utility normalized descent rate: helicopter and tilt rotor, 4,000 ft, 95°F.

(7) **Ranking.** The ranking scheme that is applied to the Utility designs is the same as that used for the SCAT designs and is presented in figures N-V-100 through N-V-102. As in the case of the SCAT, a composite score is determined and then these values are normalized using the helicopter as a reference point.

	Helicopter	Compound Helicopter	ABC	Compound ABC	TR
Long Acceleration	1.0	3.5	3.5	3.5	3.5
Long Deceleration	3.5	1.5	3.5	1.5	5.0
Turn Rate	1.0	2.0	3.5	3.5	5.0
Turn Radius	1.0	2.0	3.5	3.5	5.0
Climb Rate	1.0	3.5	3.5	3.5	3.5
Descent	5.0	1.0	3.5	2.0	3.5
Raw Score	12.5	13.50	21.0	17.5	25.5
Normalized to Helicopter	1.0	.93	.60	.71	.49

Figure N-V-100. NOE utility, 4,000 ft/95°F.

	Helicopter	Compound Helicopter	ABC	Compound ABC	TR
Long Acceleration	3.5	3.5	3.5	3.5	1.0
Long Deceleration	3.5	2.0	3.5	1.0	5.0
Turn Rate	3.0	3.0	3.0	3.0	3.0
Turn Radius	3.0	3.0	3.0	3.0	3.0
Climb Rate	3.0	1.0	3.0	3.0	5.0
Descent	4.0	5.0	3.0	1.0	2.0
Raw Score	20.0	17.5	19.0	14.5	19.0
Normalized to Helicopter	1.0	1.14	1.05	1.38	1.05

Figure N-V-101. Low speed/utility, 4,000 ft/95°F.

	Helicopter	Compound Helicopter	ABC	Compound ABC	TR
Long Acceleration	5.0	3.5	3.5	2.0	1.0
Long Deceleration	3.5	2.0	3.5	1.0	5.0
Turn Rate	4.5	2.0	4.5	3.0	1.0
Turn Radius	4.5	2.0	4.5	3.0	1.0
Climb Rate	4.5	2.0	4.5	3.0	1.0
Descent	4.0	5.0	2.5	2.5	1.0
Raw Score	26.0	16.5	23.0	14.5	10.0
Normalized to Helicopter	1.0	1.58	1.13	1.79	2.60

Figure N-V-102. Cruise/utility, 4,000 ft/95°F.

Normalizing the values, as done in figures N-V-100 through N-V-102, indicates the following preferences:

Flight Mode	Rotorcraft
NOE	Helicopter
Low Speed	Compound Helicopter
Cruise	TR

Continuing the method developed for the SCAT, the quality index for each candidate is calculated to investigate the possibility that one of the systems would be preferred above the other two. The index method is reiterated below.

$$\text{M/A Quality Index} = \frac{\text{PD HEL}}{\text{PD X}} \times \frac{\text{Cost HEL}}{\text{Cost X}} \times \frac{\text{Wt HEL}}{\text{Wt X}}$$

where: PD HEL = Ranking score of preliminary design helicopter

PD X = Ranking score of preliminary design of other rotorcraft

Cost HEL = Unit cost ($M) of PD helicopter (per 1,000 units)

Cost X = Unit cost ($M) of other PD rotorcraft (per 1,000 units)

Wt HEL = Helicopter design gross weight

Wt X = Rotorcraft design gross weight

PD HEL M/A quality index = 1.0

Flight Mode	Helicopter: Helicopter	Helicopter: Compound ABC	Helicopter: TR
NOE	1.0	.512	.377
Low Speed	1.0	.989	.809
Cruise	1.0	1.285	1.999

Figure N-V-103. M/A quality index, 4,000 ft/95°F.

The results presented in figure N-V-103 show the helicopter to be the preferred system in two of the three categories. The conclusion of the Utility analysis is that the preferred system is the helicopter primarily because mission success is largely based on terminal area operations, an area where the helicopter is the more preferred system.

c. SCAT Designs (2,000 ft/70°F). The maneuverability and agility capabilities for the SCAT at 2,000 ft/70°F are presented in figures N-V-104 through N-V-127. The normalized comparisons are presented in figures N-V-128 through N-V-151. Other than to say that trends are similar to those at 4,000 ft/95°F, no further discussion is developed.

d. Utility Designs. The maneuverability and agility capabilities for the utility at 2,000 ft/70°F are presented in figures N-V-152 through N-V-173. The normalized comparisons are presented in figures N-V-174 through N-V-197. The above comment relative to the SCAT applies to the Utility.

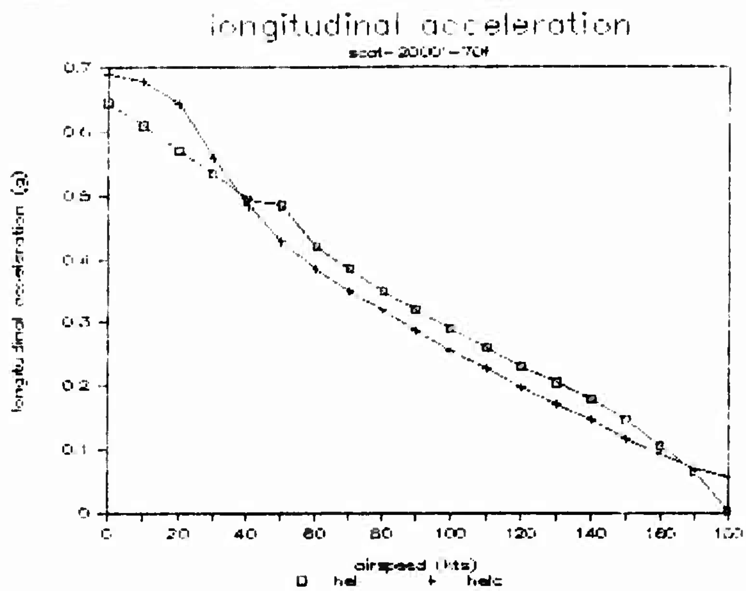

Figure N-V-104. SCAT longitudinal acceleration: helicopter and helicopter-compound, 2,000 ft, 70°F.

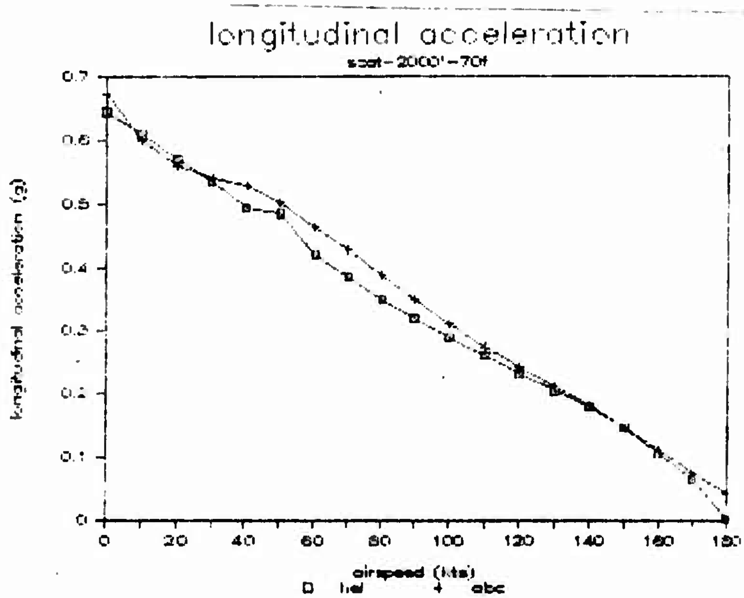

Figure N-V-105. SCAT longitudinal acceleration: helicopter and ABC, 2,000 ft, 70°F.

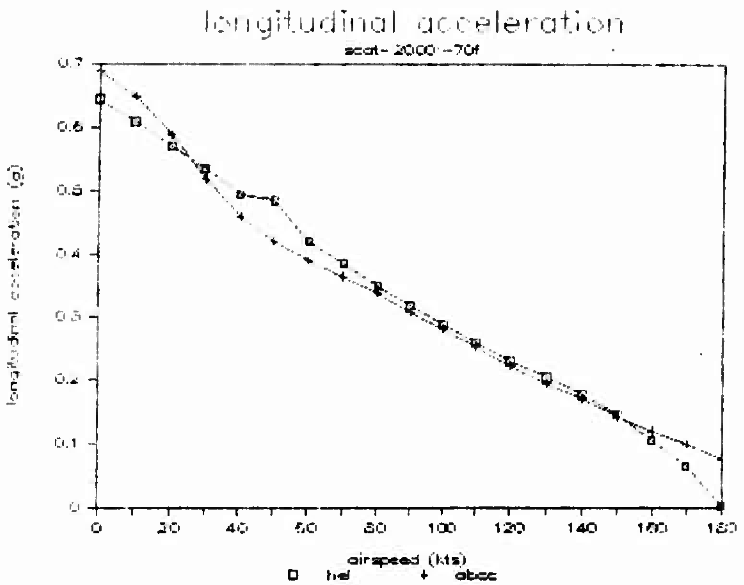

Figure N-V-106. SCAT longitudinal acceleration: helicopter and ABC-compound, 2,000 ft, 70°F.

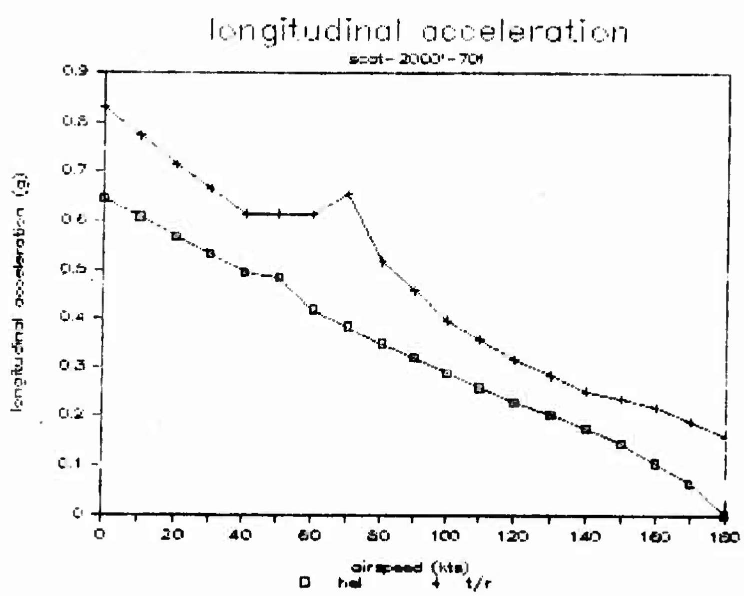

Figure N-V-107. SCAT longitudinal acceleration: helicopter and tilt rotor, 2,000 ft, 70°F.

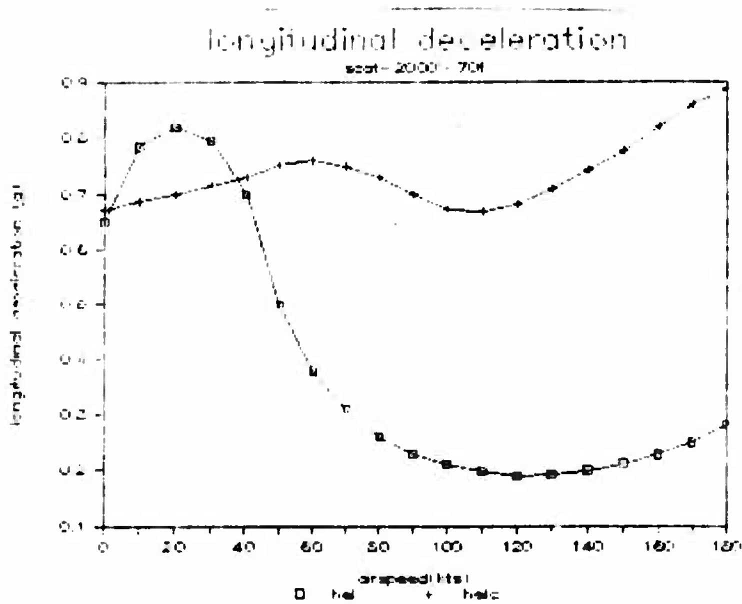

Figure N-V-108. SCAT longitudinal deceleration: helicopter and helicopter-compound, 2,000 ft, 70°F.

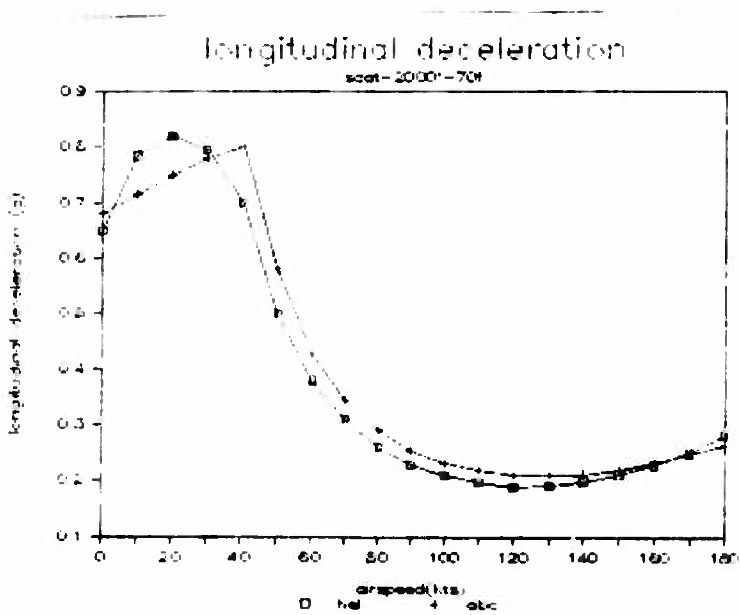

Figure N-V-109. SCAT longitudinal deceleration: helicopter and ABC, 2,000 ft, 70°F.

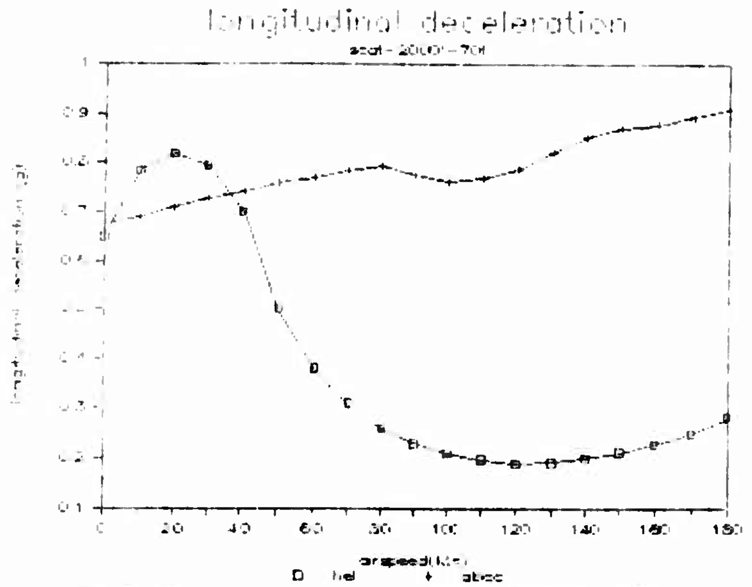

Figure N-V-110. SCAT longitudinal deceleration: helicopter and ABC-compound, 2,000 ft, 70°F.

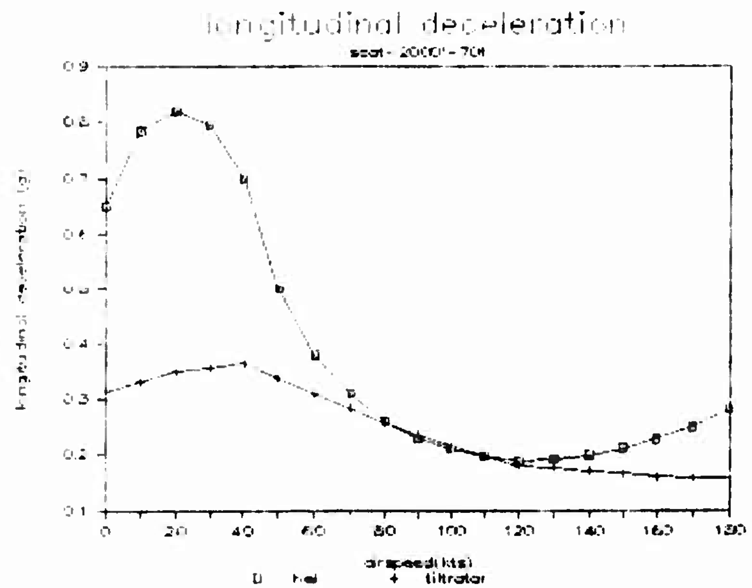

Figure N-V-111. SCAT longitudinal deceleration: helicopter and tilt rotor, 2,000 ft, 70°F.

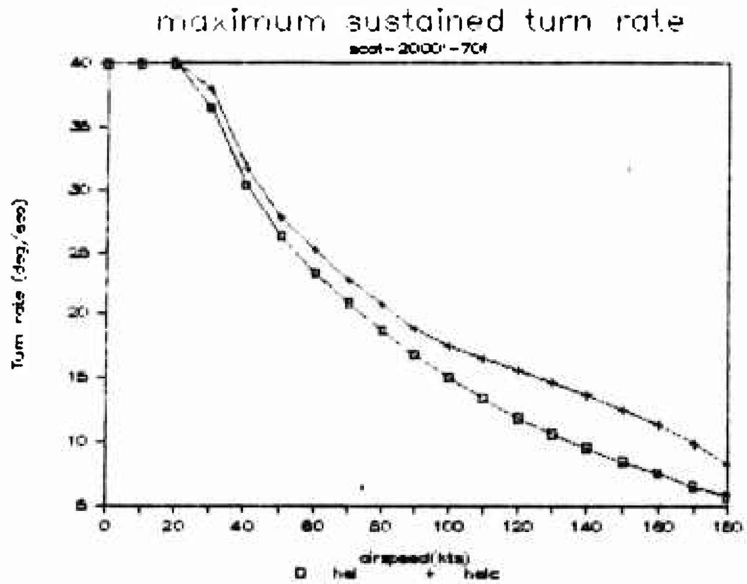

Figure N-V-112. SCAT turn rate: helicopter and helicopter-compound, 2,000 ft, 70°F.

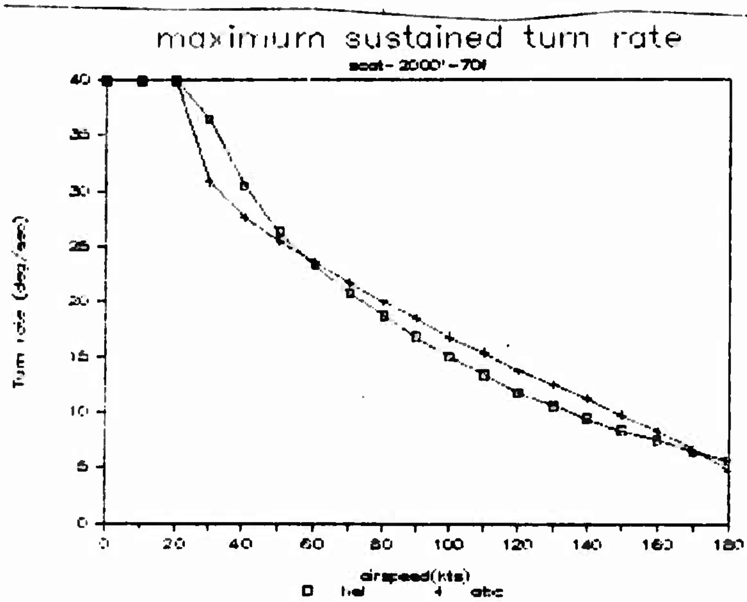

Figure N-V-113. SCAT turn rate: helicopter and ABC, 2,000 ft, 70°F.

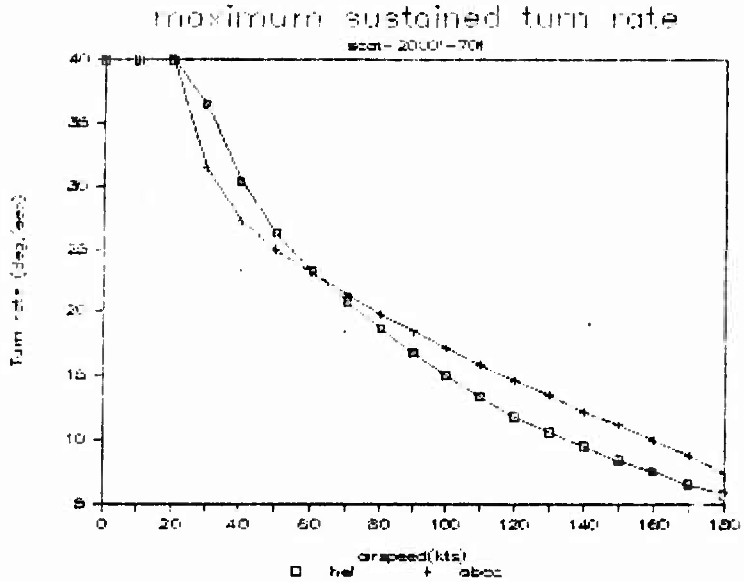

Figure N-V-114. SCAT turn rate: helicopter and ABC-compound, 2,000 ft, 70°F.

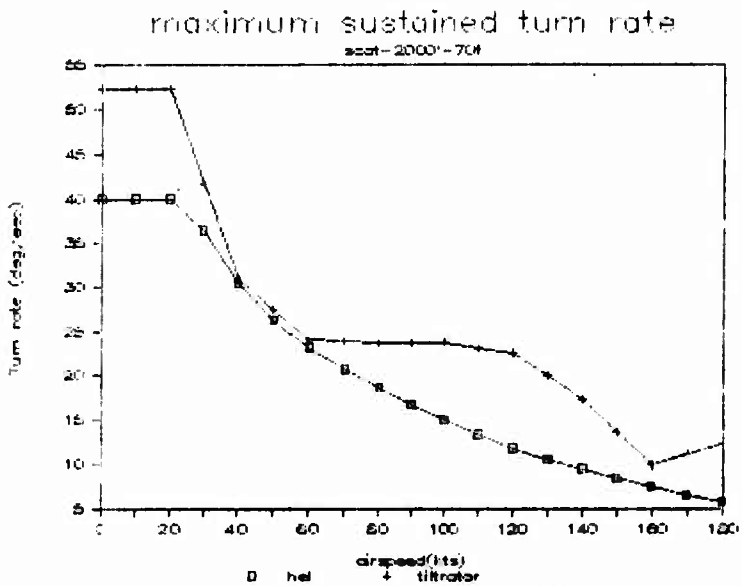

Figure N-V-115. SCAT turn rate: helicopter and tilt rotor, 2,000 ft, 70°F.

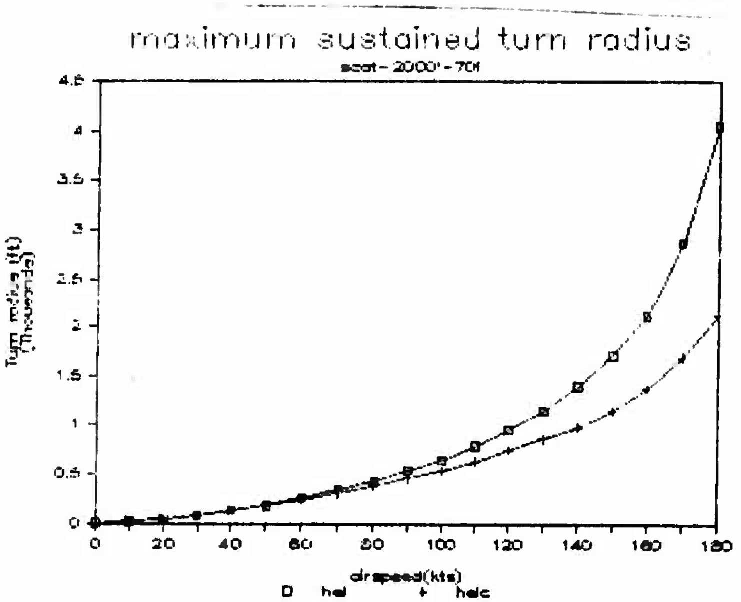

Figure N-V-116. SCAT turn radius: helicopter and helicopter-compound, 2,000 ft, 70°F.

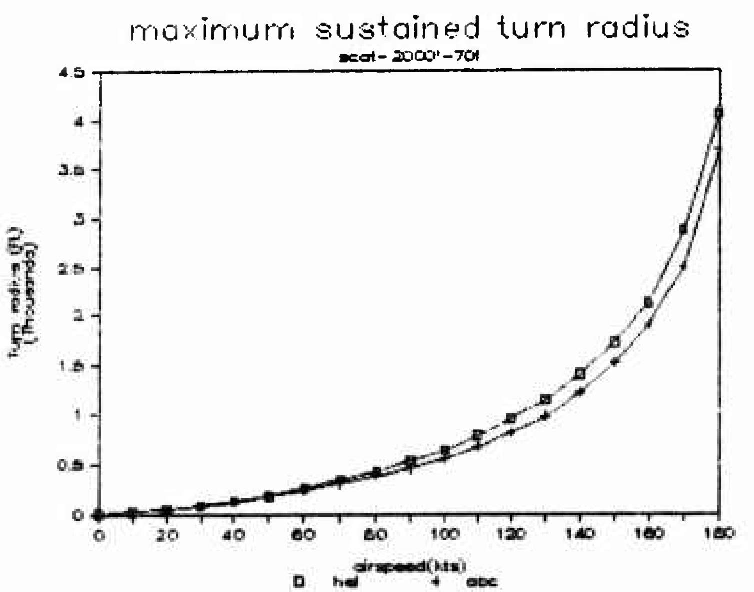

Figure N-V-117. SCAT turn radius: helicopter and ABC, 2,000 ft, 70°F.

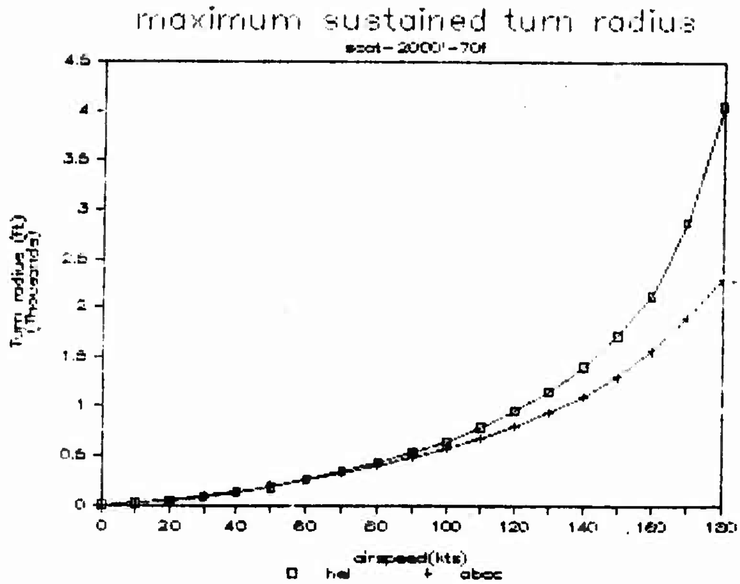

Figure N-V-118. SCAT turn radius: helicopter and ABC-compound, 2,000 ft, 70°F.

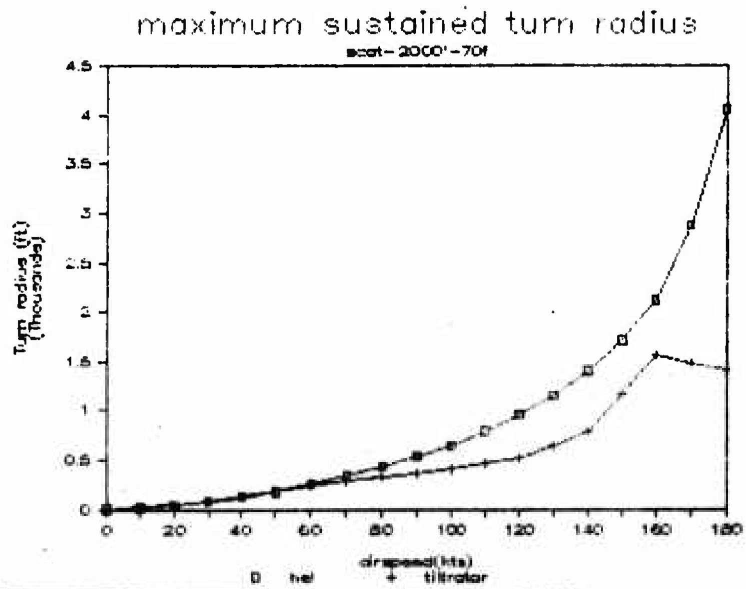

Figure N-V-119. SCAT turn radius: helicopter and tilt rotor, 2,000 ft, 70°F.

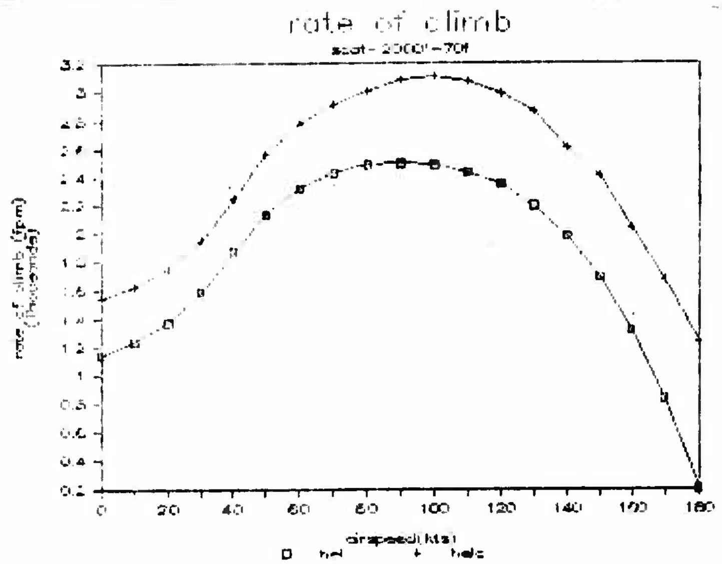

Figure N-V-120. SCAT climb rate: helicopter and helicopter-compound, 2,000 ft, 70°F.

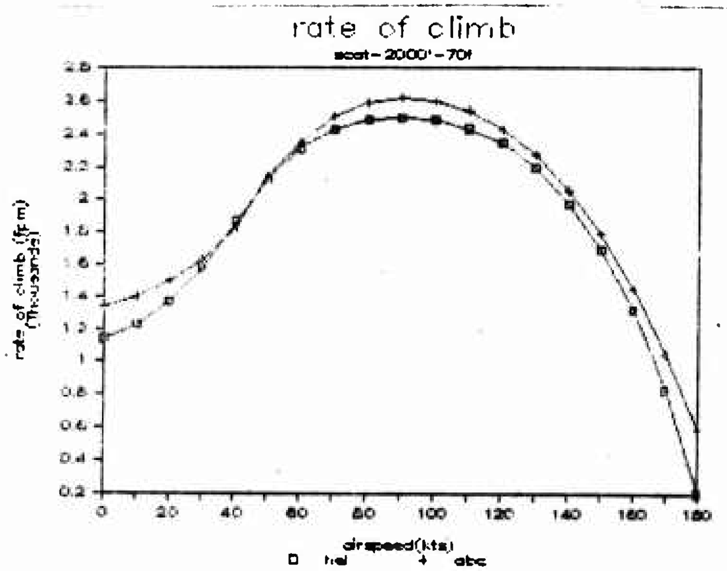

Figure N-V-121. SCAT climb rate: helicopter and ABC, 2,000 ft, 70°F.

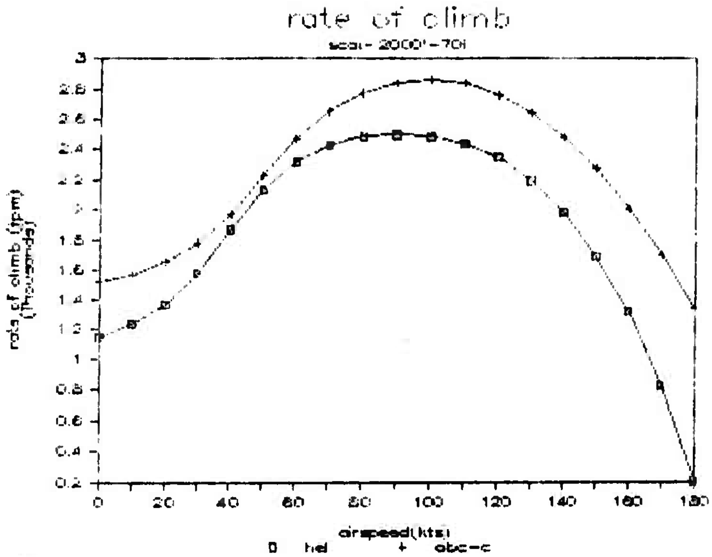

Figure N-V-122. SCAT climb rate: helicopter and ABC-compound, 2,000 ft, 70°F.

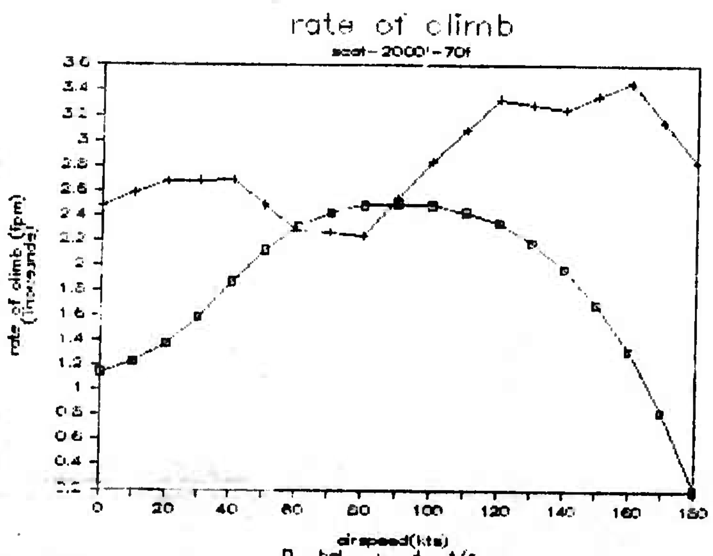

Figure N-V-123. SCAT climb rate: helicopter and tilt rotor, 2,000 ft, 70°F.

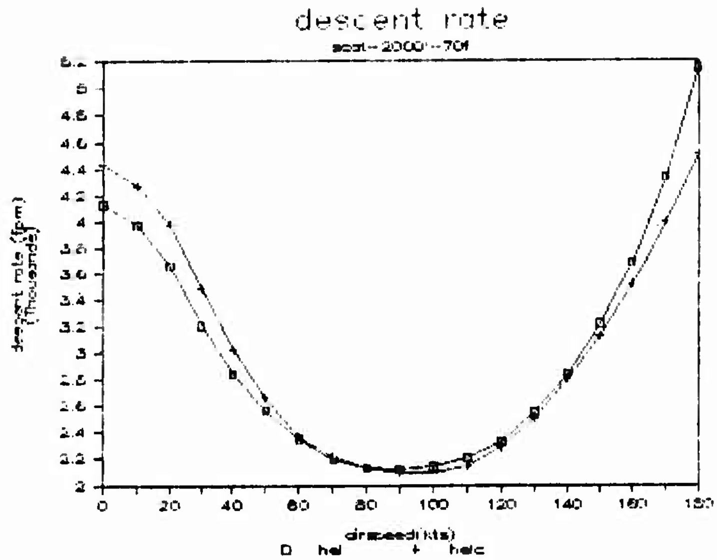

Figure N-V-124. SCAT descent rate: helicopter and helicopter-compound, 2,000 ft, 70°F.

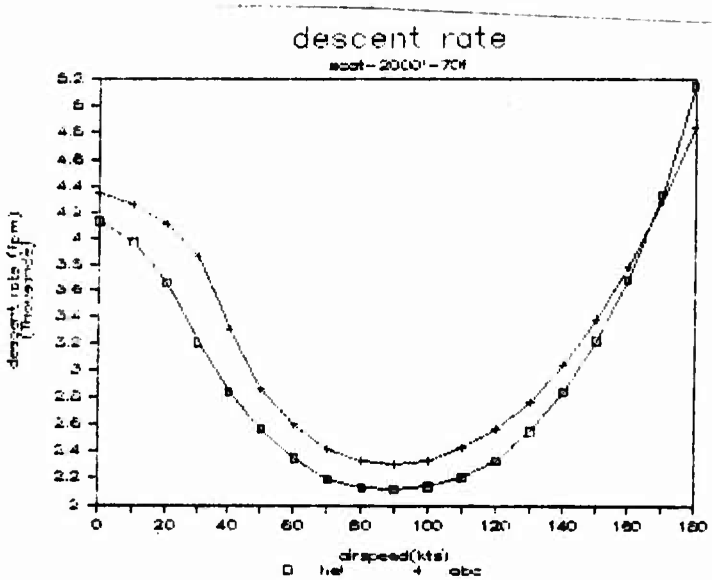

Figure N-V-125. SCAT descent rate: helicopter and ABC, 2,000 ft, 70°F.

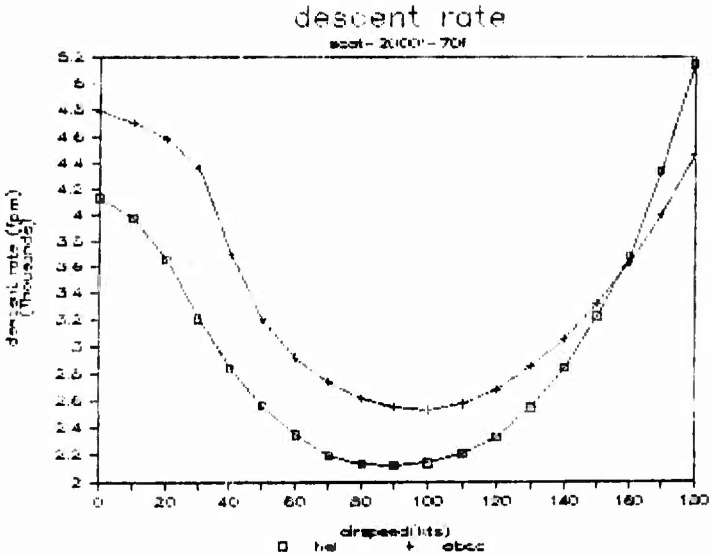

Figure N-V-126. SCAT descent rate: helicopter and ABC-compound, 2,000 ft, 70°F.

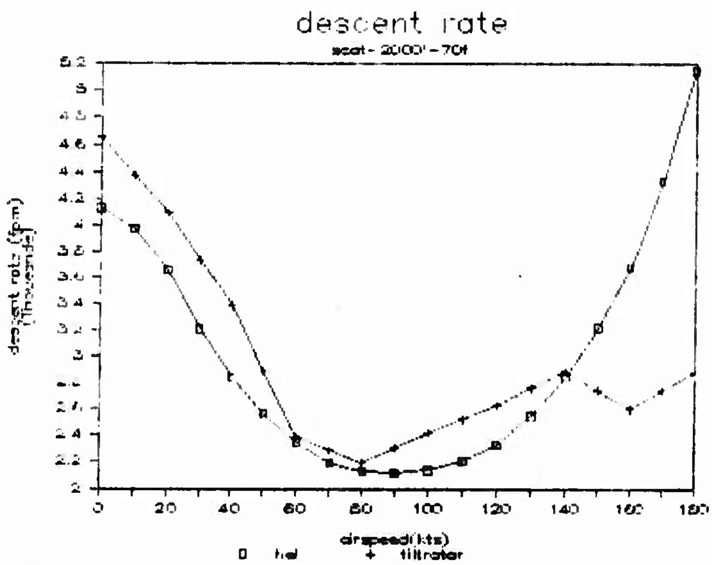

Figure N-V-127. SCAT descent rate: helicopter and tilt rotor, 2,000 ft, 70°F.

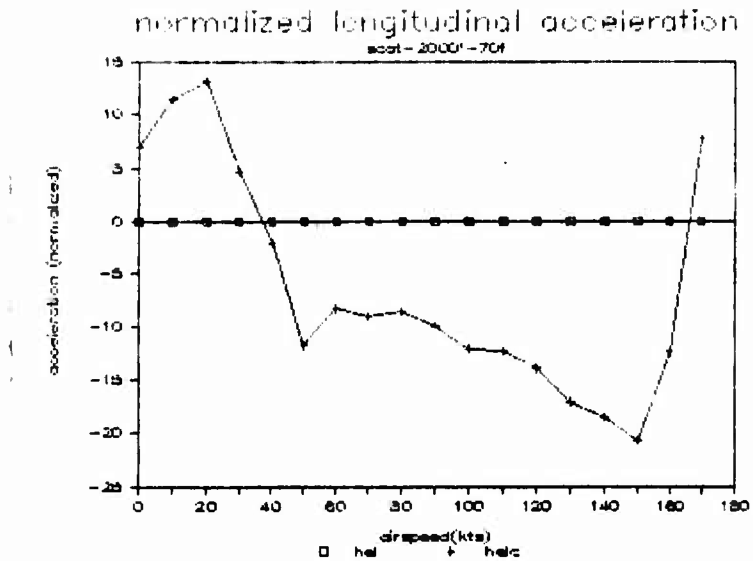

Figure N-V-128. SCAT normalized longitudinal acceleration: helicopter and helicopter-compound, 2,000 ft, 70°F.

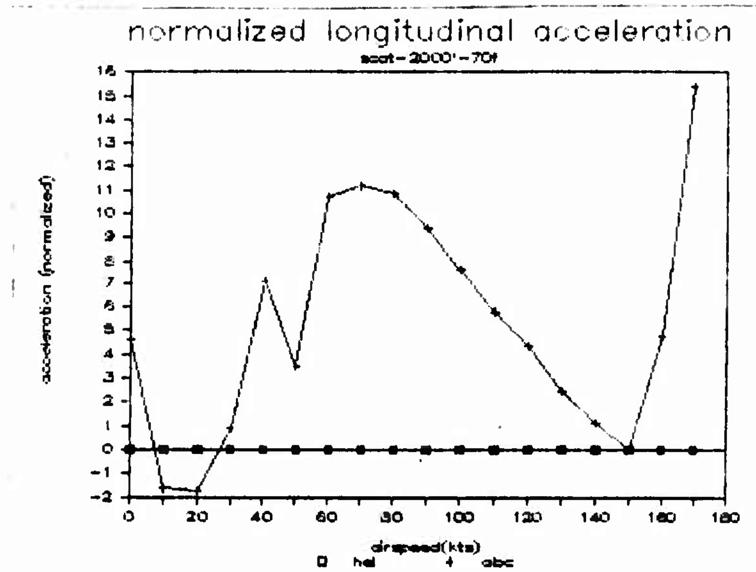

Figure N-V-129. SCAT normalized longitudinal acceleration: helicopter and ABC, 2,000 ft, 70°F.

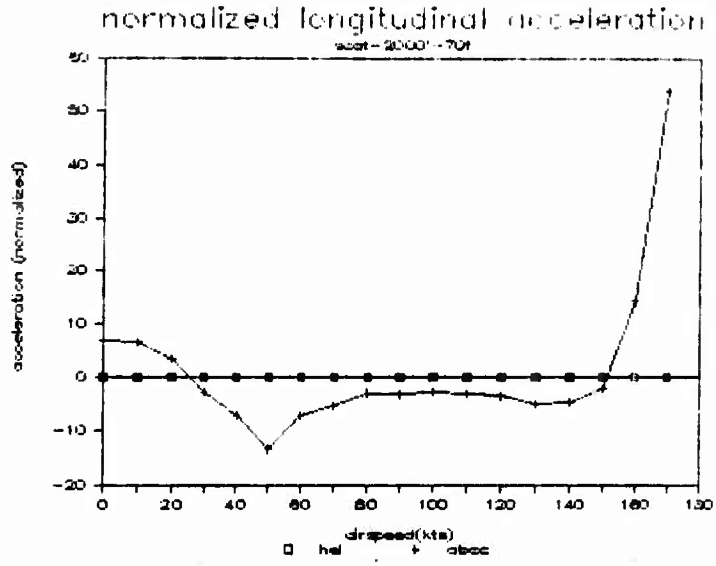

Figure N-V-130. SCAT normalized longitudinal acceleration: helicopter and ABC-compound, 2,000 ft, 70°F.

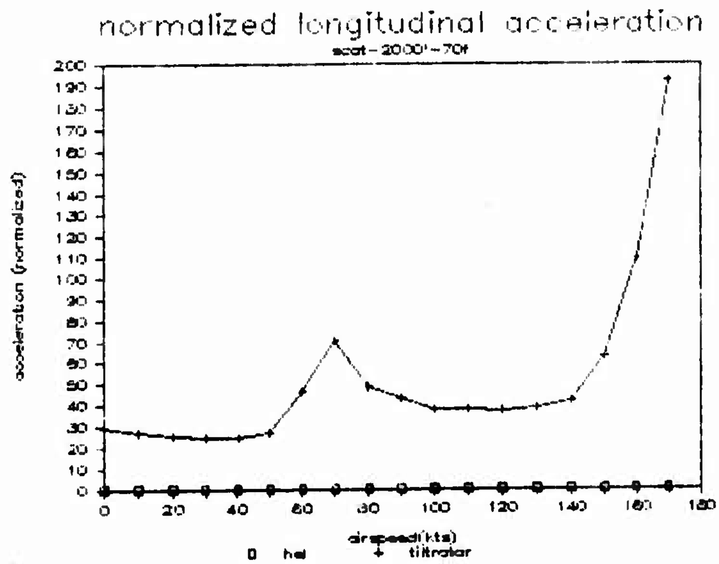

Figure N-V-131. SCAT normalized longitudinal acceleration: helicopter and tilt rotor, 2,000 ft, 70°F.

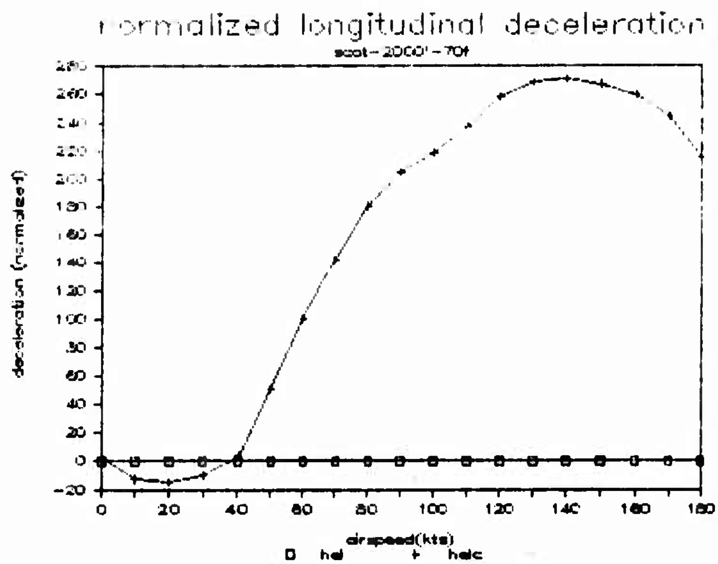

Figure N-V-132. SCAT normalized longitudinal deceleration: helicopter and helicopter-compound, 2,000 ft, 70°F.

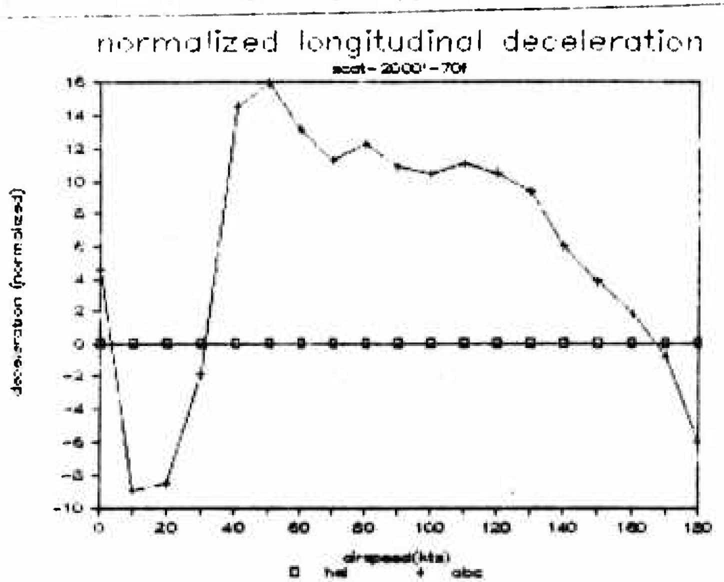

Figure N-V-133. SCAT normalized longitudinal deceleration: helicopter and ABC, 2,000 ft, 70°F.

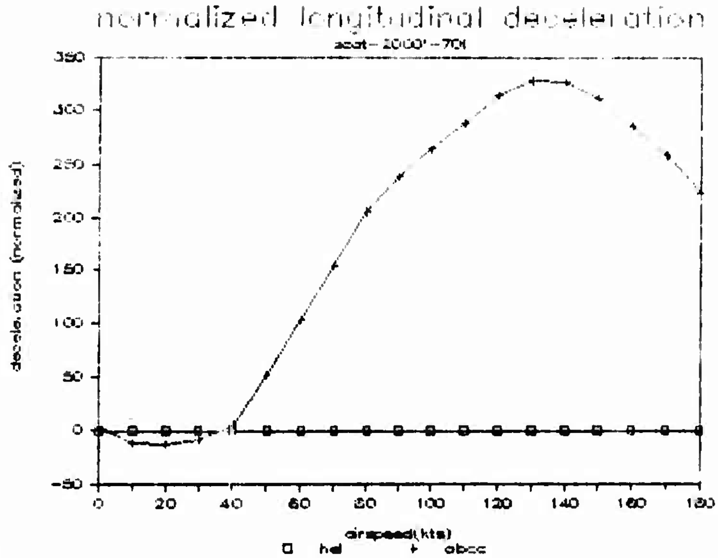

Figure N-V-134. SCAT normalized longitudinal deceleration: helicopter and ABC-compound, 2,000 ft, 70°F.

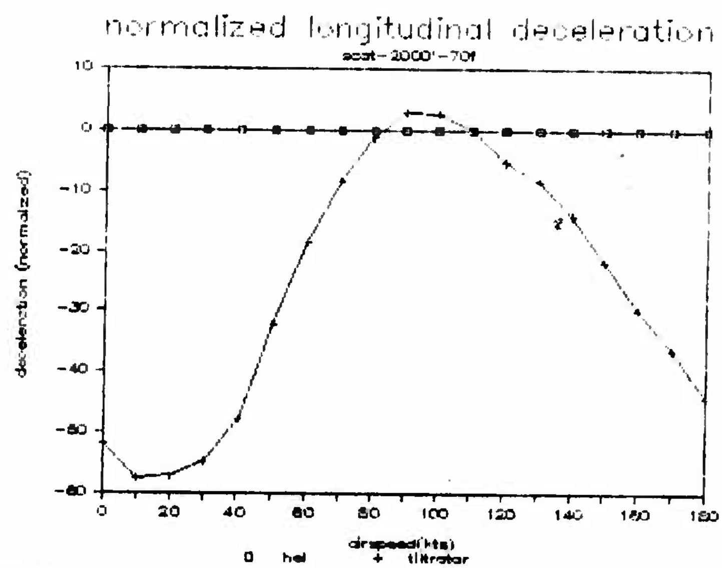

Figure N-V-135. SCAT normalized longitudinal deceleration: helicopter and tilt rotor, 2,000 ft, 70°F.

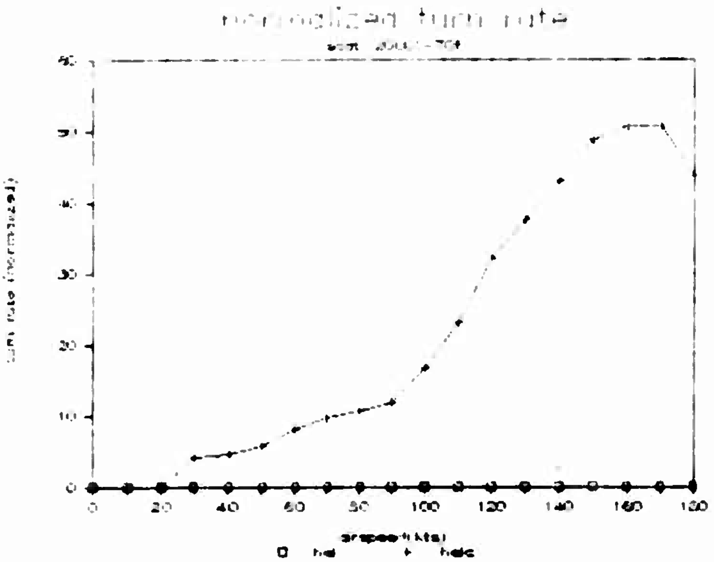

Figure N-V-136. SCAT normalized turn rate: helicopter and helicopter-compound, 2,000 ft, 70°F.

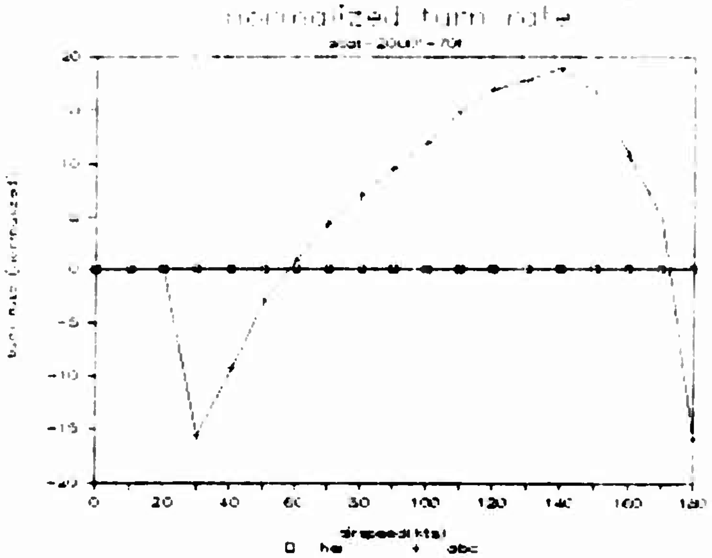

Figure N-V-137. SCAT normalized turn rate: helicopter and ABC, 2,000 ft, 70°F.

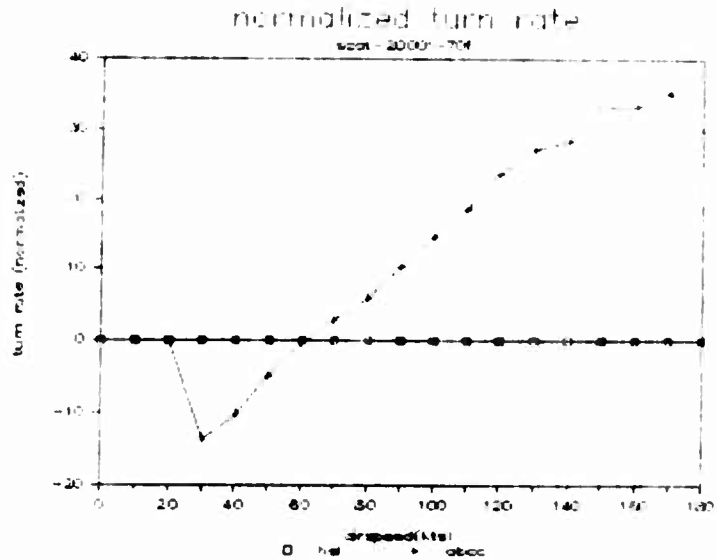

Figure N-V-138. SCAT normalized turn rate: helicopter and ABC-compound, 2,000 ft, 70°F.

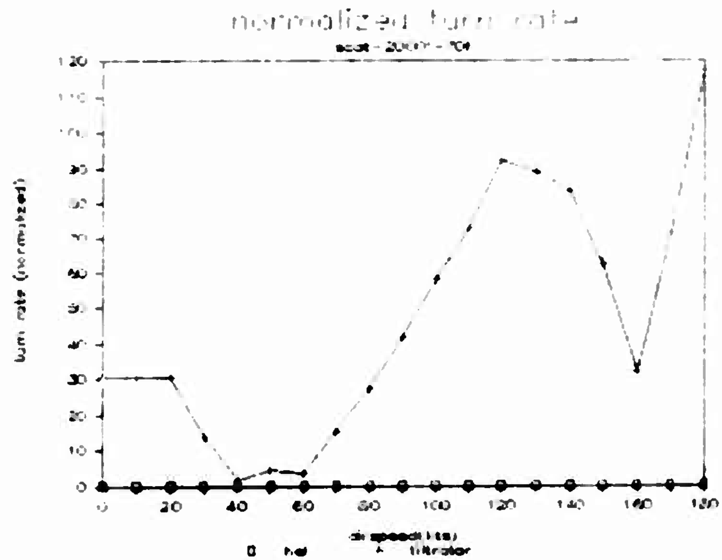

Figure N-V-139. SCAT normalized turn rate: helicopter and tilt rotor, 2,000 ft, 70°F.

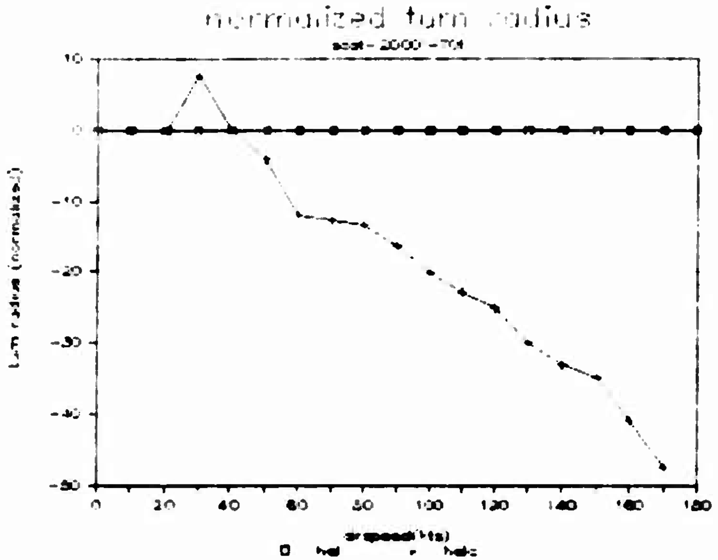

Figure N-V-140. SCAT normalized turn radius: helicopter and helicopter-compound, 2,000 ft, 70°F.

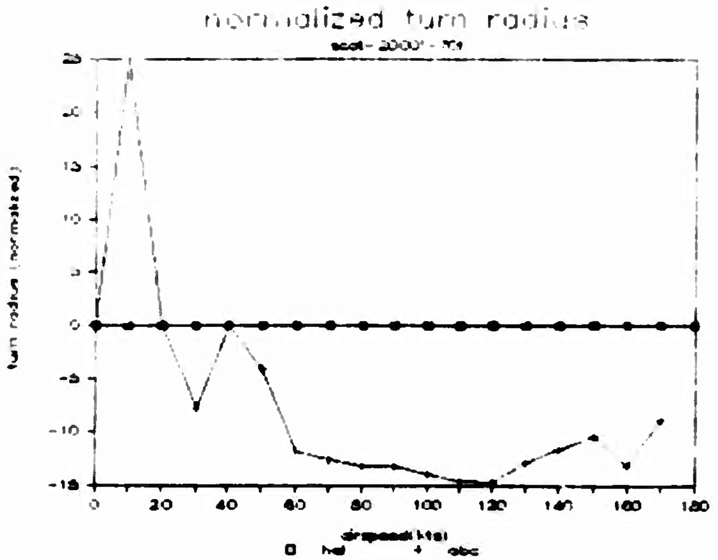

Figure N-V-141. SCAT normalized turn radius: helicopter and ABC, 2,000 ft, 70°F.

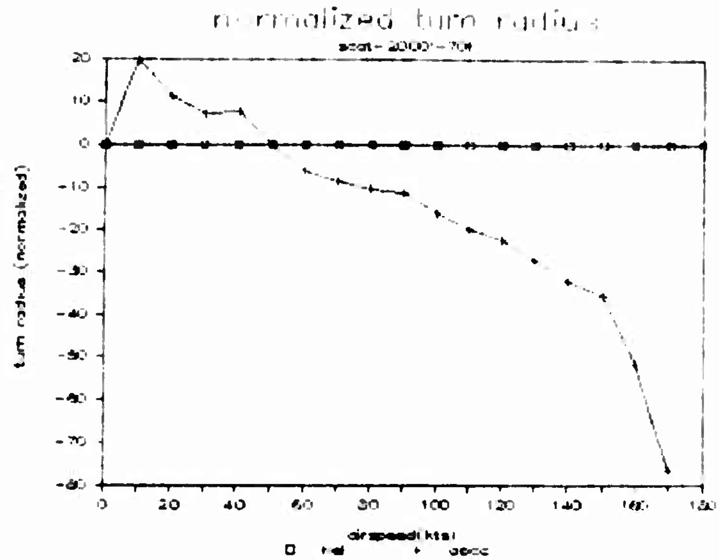

Figure N-V-142. SCAT normalized turn radius: helicopter and ABC-compound, 2,000 ft, 70°F.

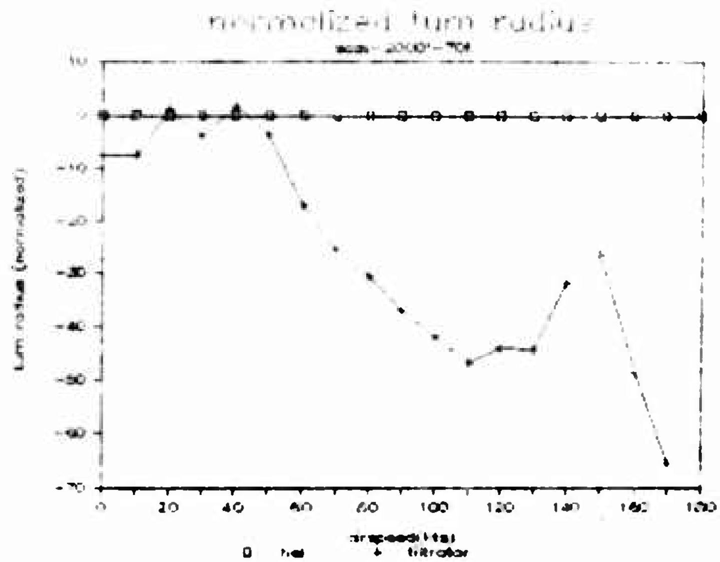

Figure N-V-143. SCAT normalized turn radius: helicopter and tilt rotor, 2,000 ft, 70°F.

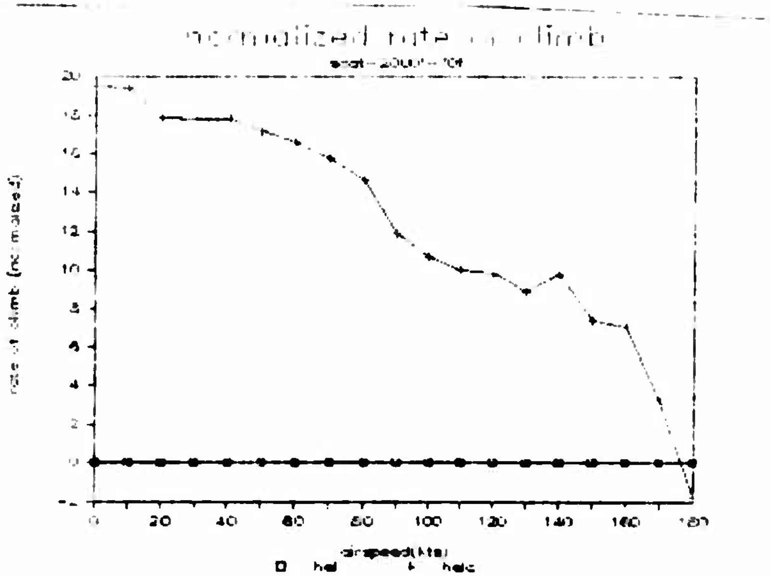

Figure N-V-144. SCAT normalized climb rate: helicopter and helicopter-compound, 2,000 ft, 70°F.

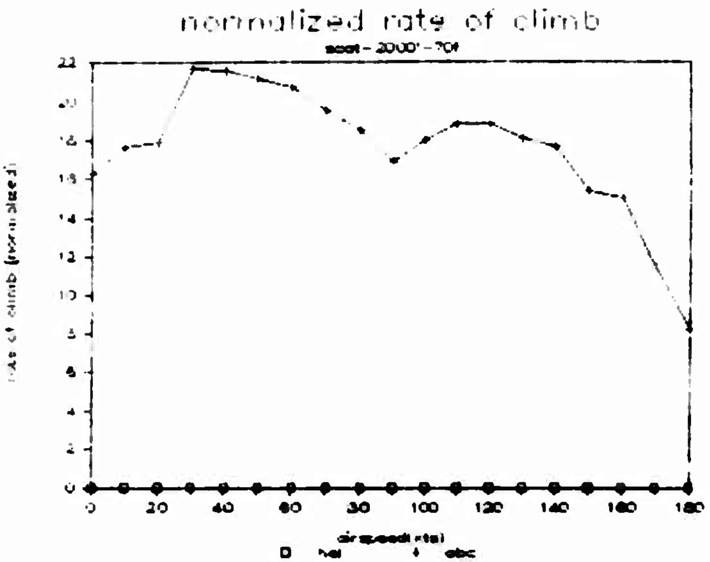

Figure N-V-145. SCAT normalized climb rate: helicopter and ABC, 2,000 ft, 70°F.

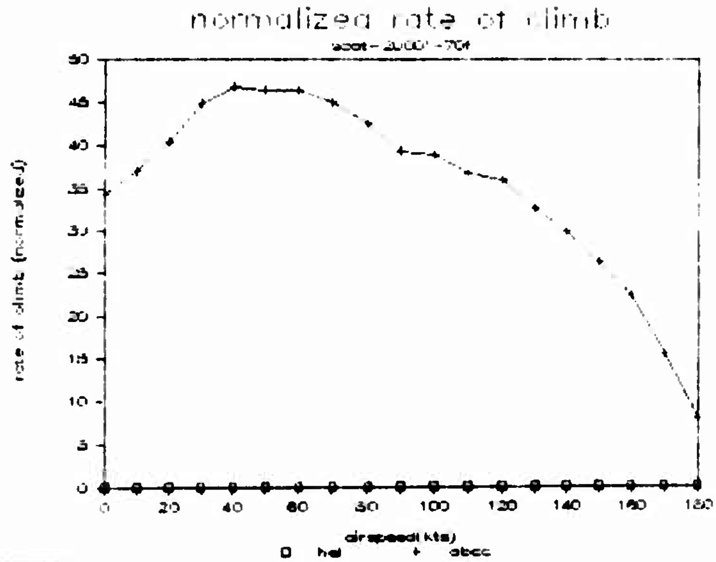

Figure N-V-146. SCAT normalized climb rate: helicopter and ABC-compound, 2,000 ft, 70°F.

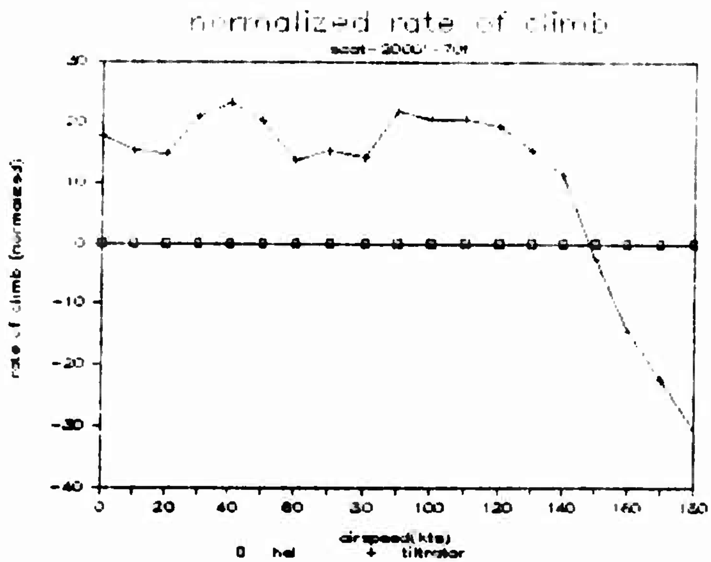

Figure N-V-147. SCAT normalized climb rate: helicopter and tilt rotor, 2,000 ft, 70°F.

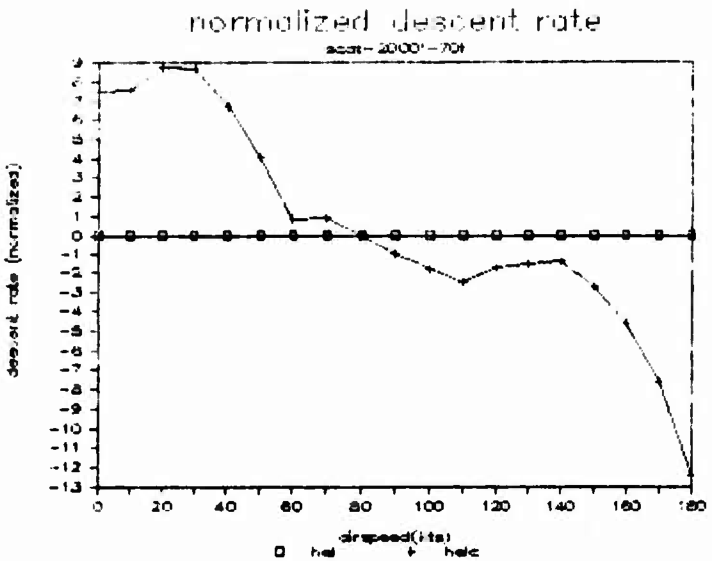

Figure N-V-148. SCAT normalized descent rate: helicopter and helicopter-compound, 2,000 ft, 70°F.

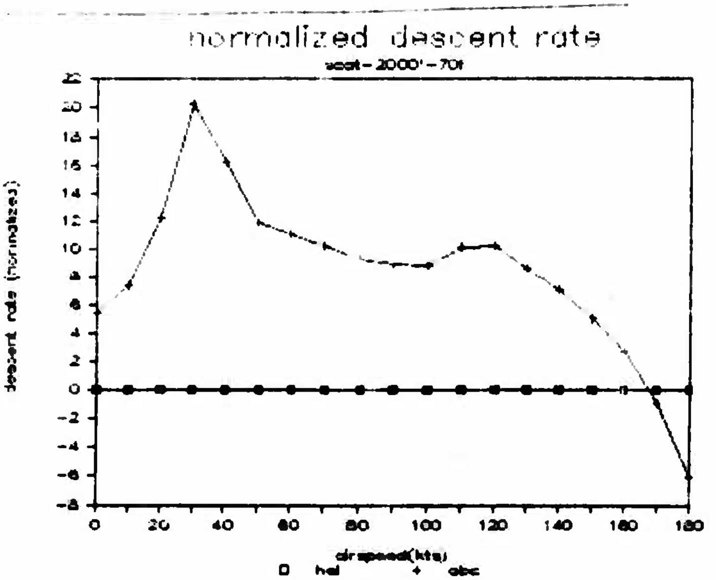

Figure N-V-149. SCAT normalized descent rate: helicopter and ABC, 2,000 ft, 70°F.

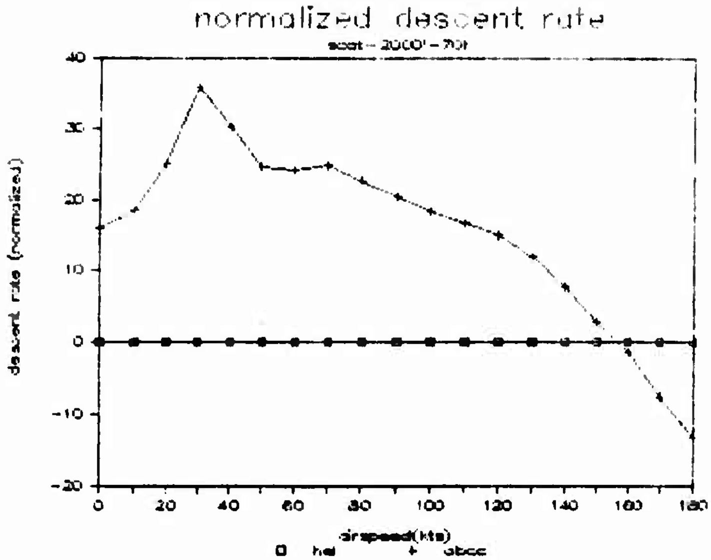

Figure N-V-150. SCAT normalized descent rate: helicopter and ABC-compound, 2,000 ft, 70°F.

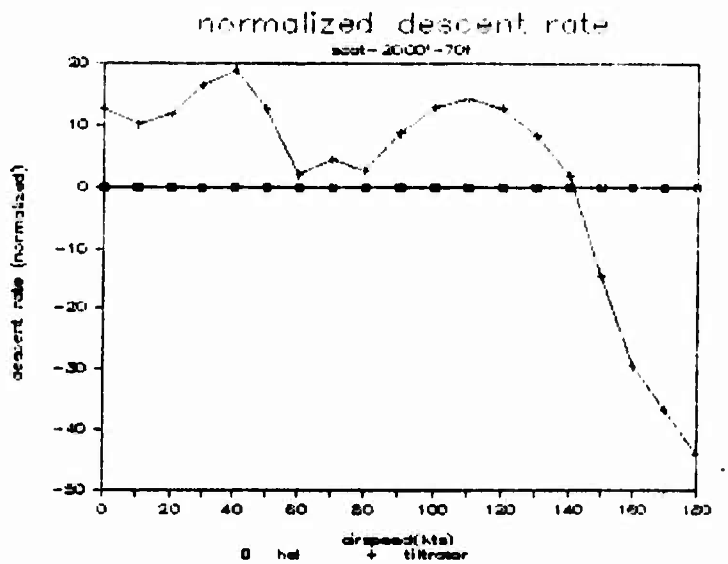

Figure N-V-151. SCAT normalized descent rate: helicopter and tilt rotor, 2,000 ft, 70°F.

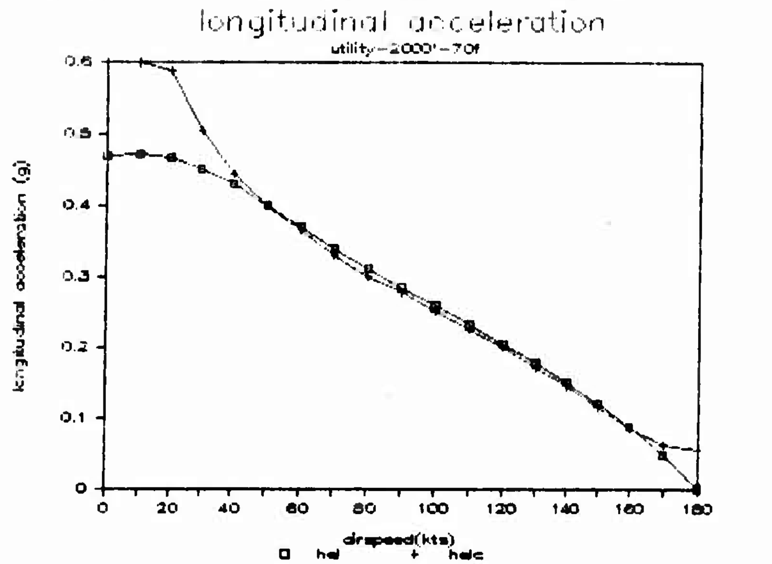

Figure N-V-152. Utility longitudinal acceleration: helicopter and helicopter-compound, 2,000 ft, 70°F.

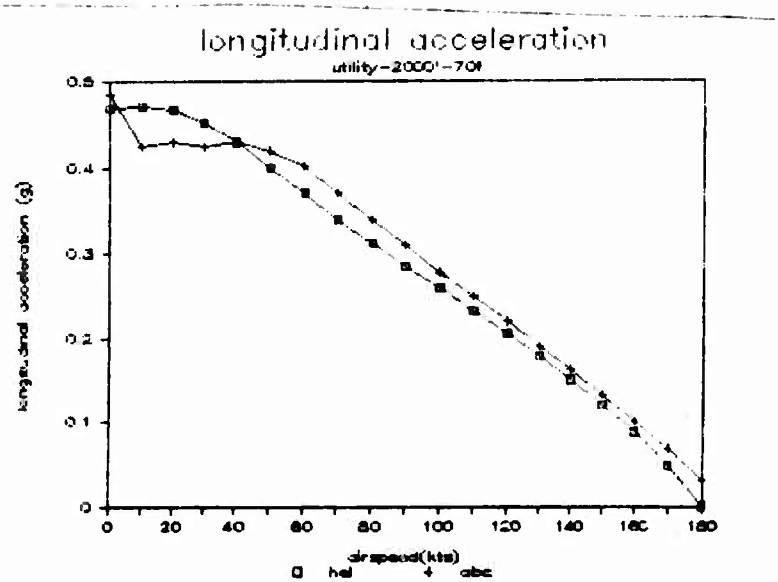

Figure N-V-153. Utility longitudinal acceleration: helicopter and ABC, 2,000 ft, 70°F.

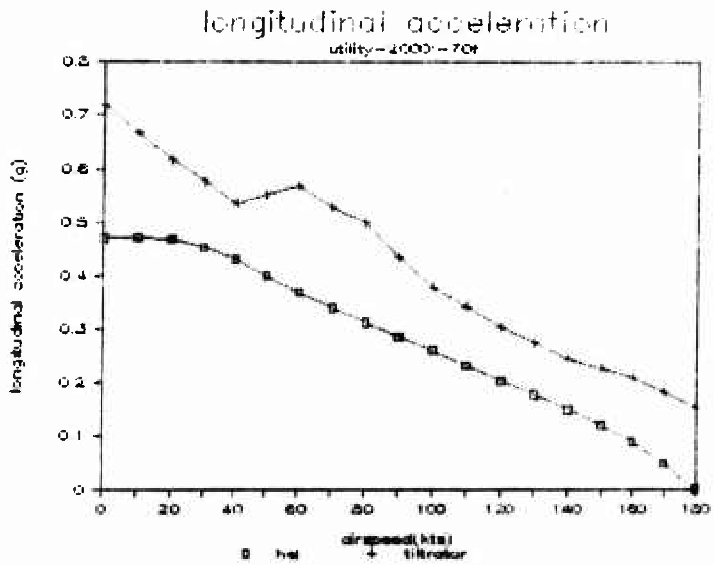

Figure N-V-154. Utility longitudinal acceleration: helicopter and tilt rotor, 2,000 ft, 70°F.

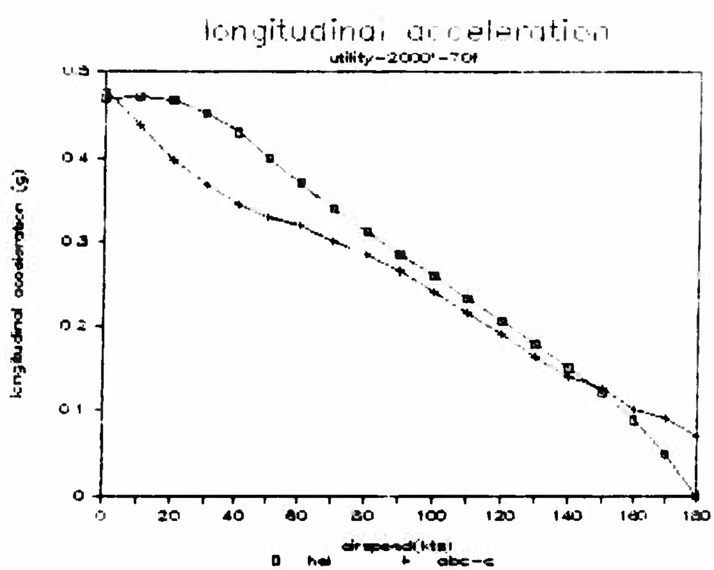

Figure N-V-155. Utility longitudinal acceleration: helicopter and ABC-compound, 2,000 ft, 70°F.

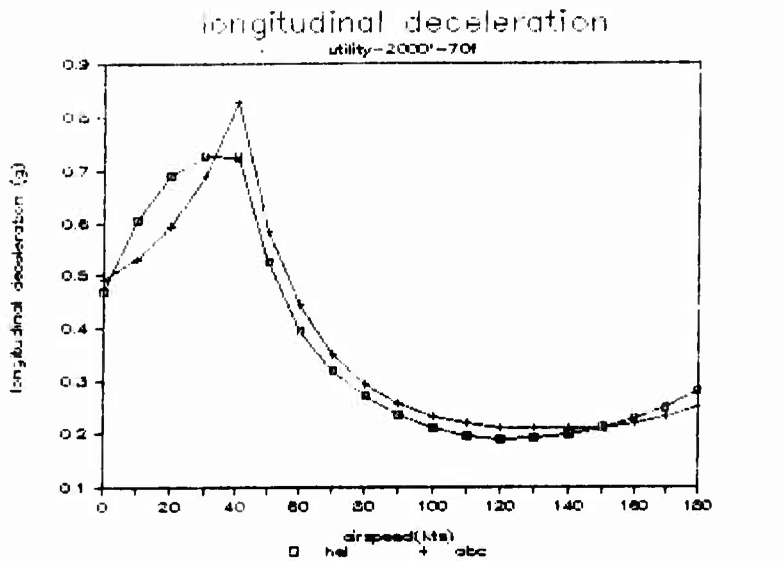

Figure N-V-156. Utility longitudinal deceleration: helicopter and ABC, 2,000 ft, 70°F.

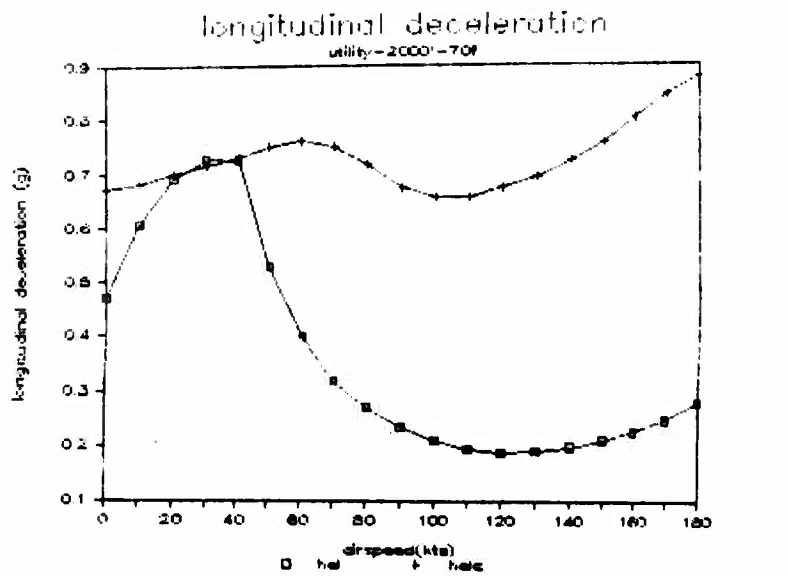

Figure N-V-157. Utility longitudinal deceleration: helicopter and helicopter-compound, 2,000 ft, 70°F.

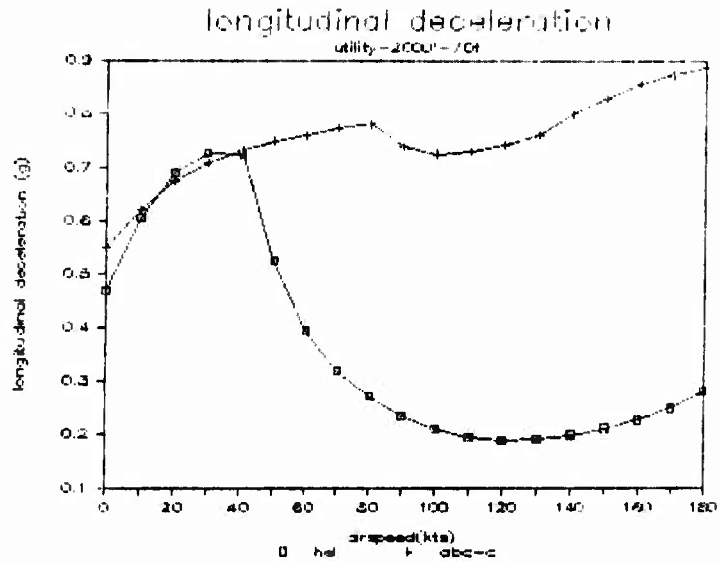

Figure N-V-158. Utility longitudinal deceleration: helicopter and ABC-compound, 2,000 ft, 70°F.

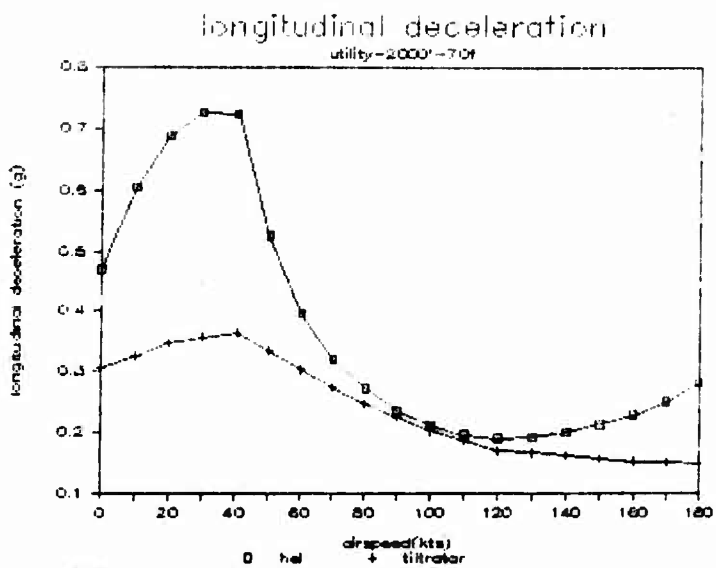

Figure N-V-159. Utility longitudinal deceleration: helicopter and tilt rotor, 2,000 ft, 70°F.

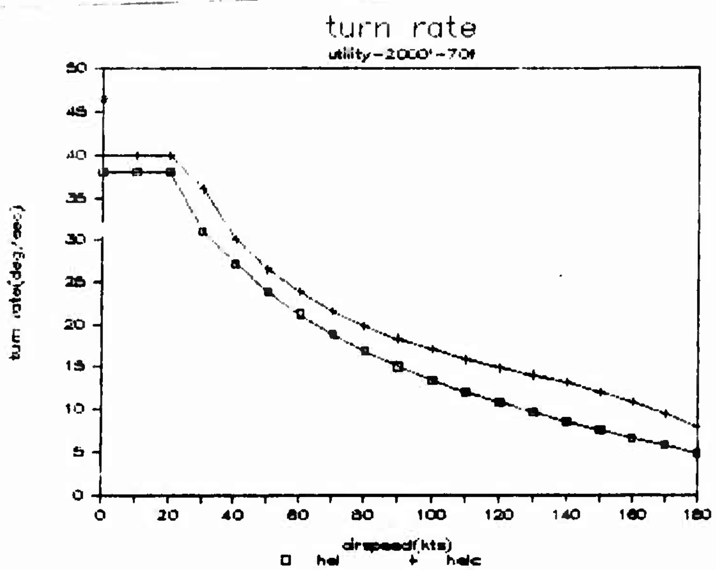

Figure N-V-160. Utility turn rate: helicopter and helicopter-compound, 2,000 ft, 70°F.

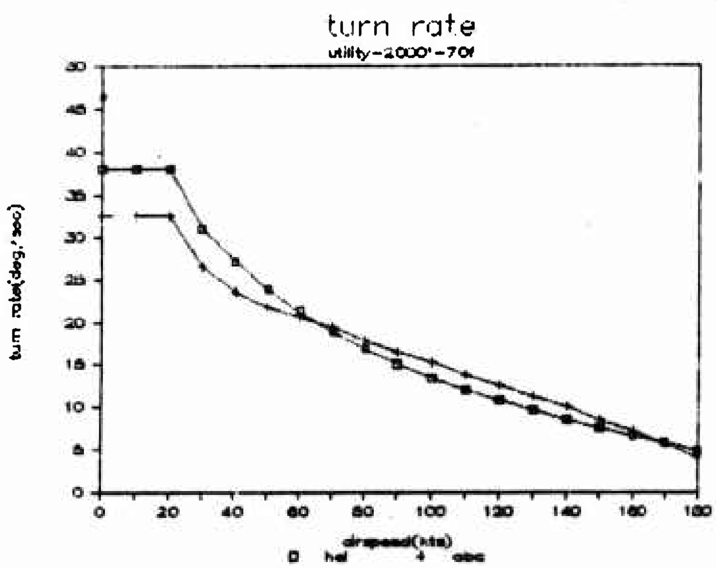

Figure N-V-161. Utility turn rate: helicopter and ABC, 2,000 ft, 70°F.

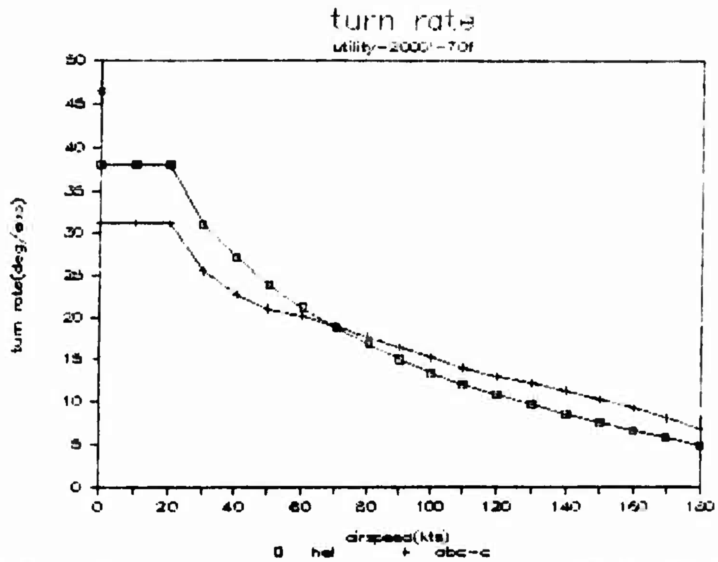

Figure N-V-162. Utility turn rate: helicopter and ABC-compound, 2,000 ft, 70°F.

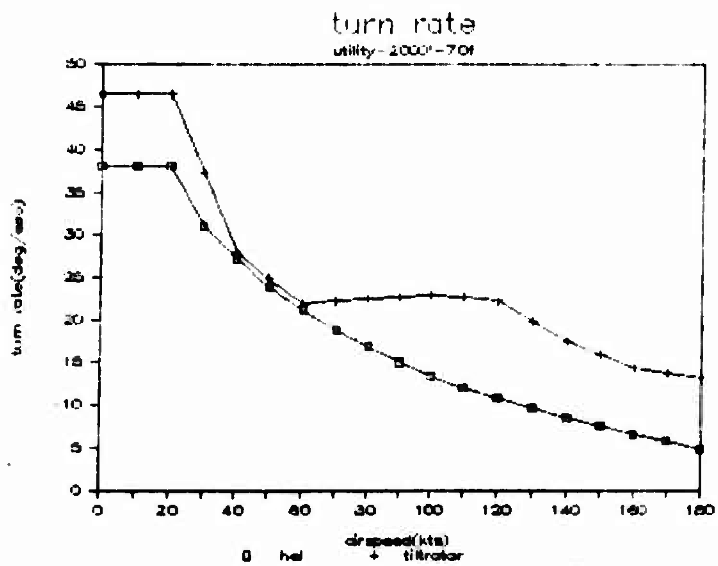

Figure N-V-163. Utility turn rate: helicopter and tilt rotor, 2,000 ft, 70°F.

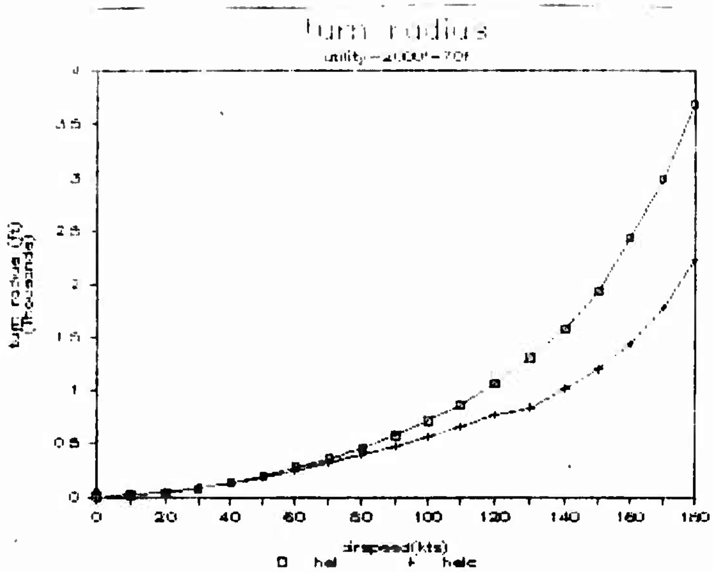

Figure N-V-164. Utility turn radius: helicopter and helicopter-compound, 2,000 ft, 70°F.

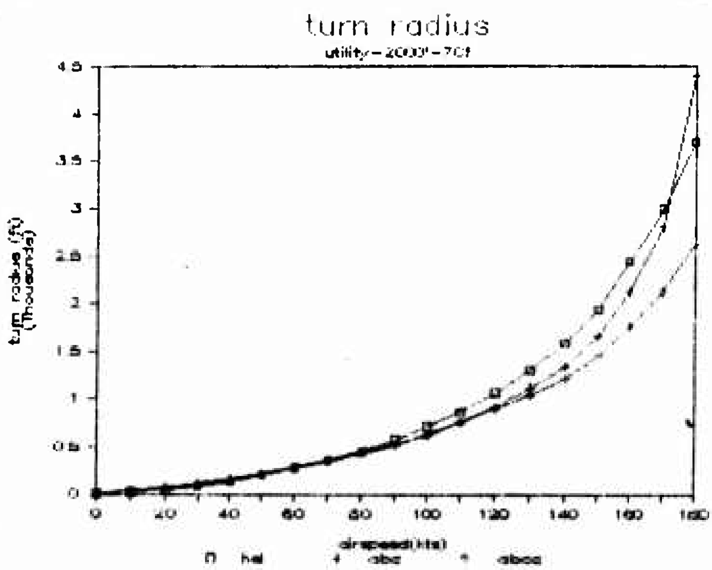

Figure N-V-165. Utility turn radius: helicopter, ABC, and ABC-compound, 2,000 ft, 70°F.

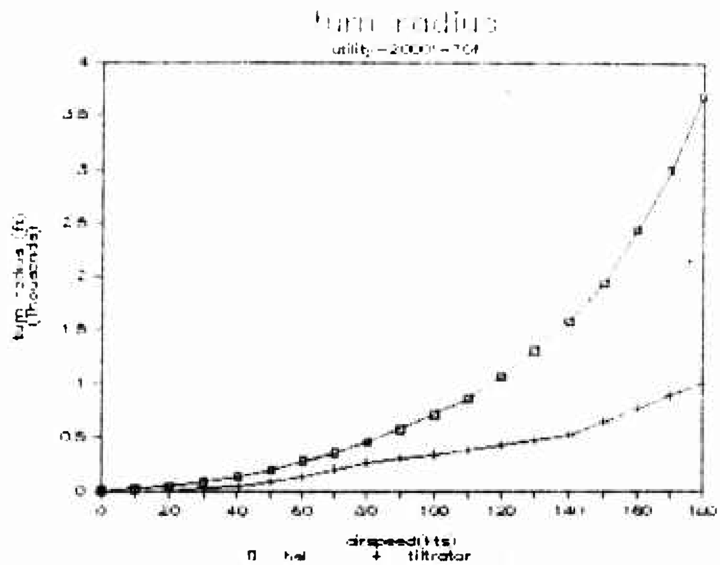

Figure N-V-166. Utility turn radius: helicopter and tilt rotor, 2,000 ft, 70°F.

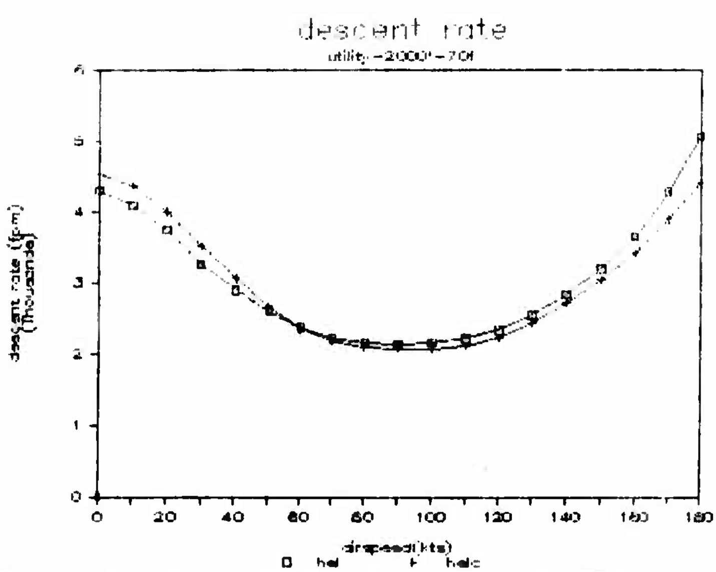

Figure N-V-167. Utility descent rate: helicopter and helicopter-compound, 2,000 ft, 70°F.

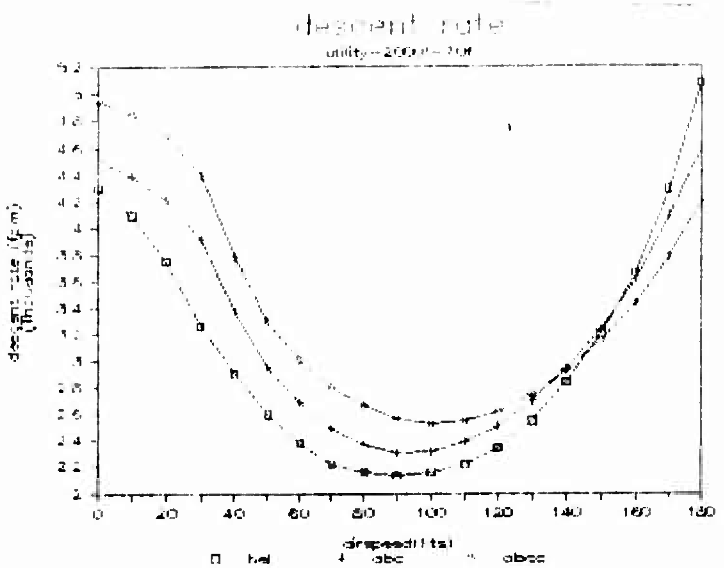

Figure N-V-168. Utility descent rate: helicopter, ABC, and ABC-compound, 2,000 ft, 70°F.

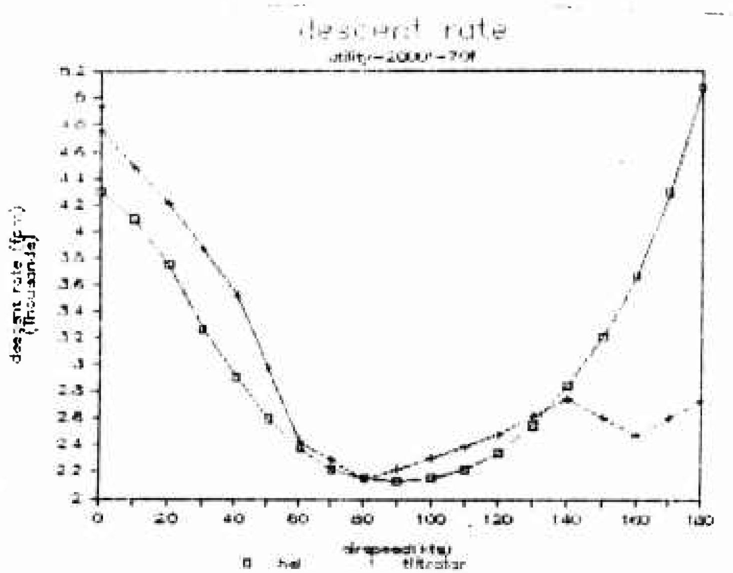

Figure N-V-169. Utility descent rate: helicopter and tilt rotor, 2,000 ft, 70°F.

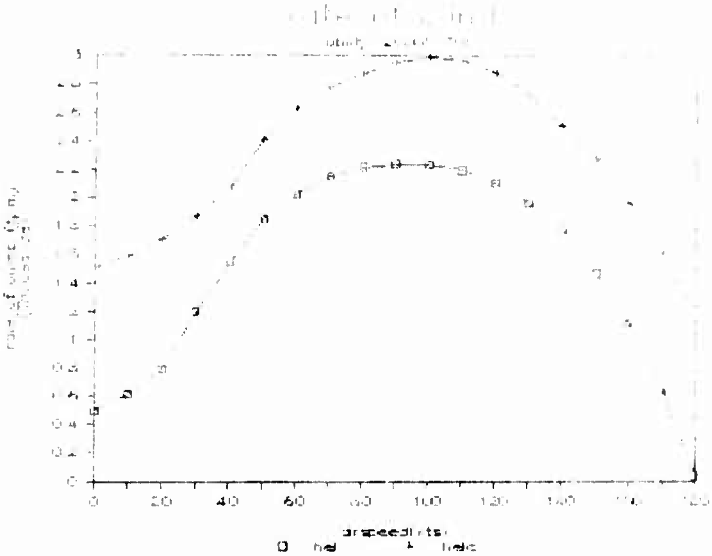

Figure N-V-170. Utility climb rate: helicopter and helicopter-compound, 2,000 ft, 70°F.

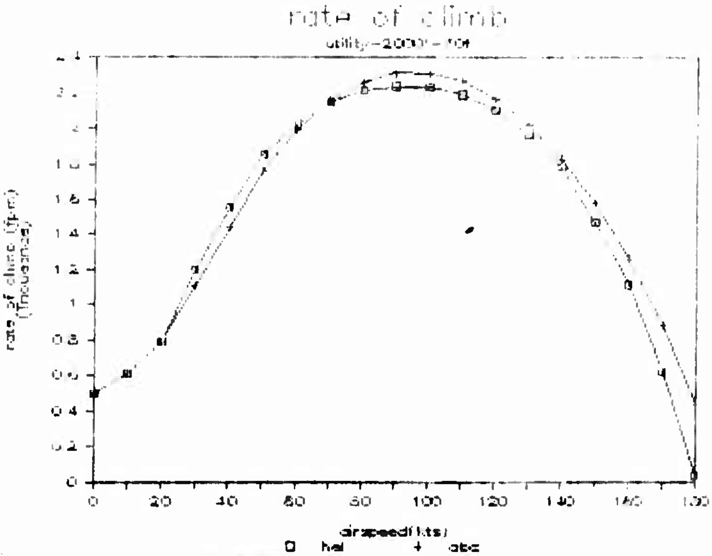

Figure N-V-171. Utility climb rate: helicopter and ABC, 2,000 ft, 70°F.

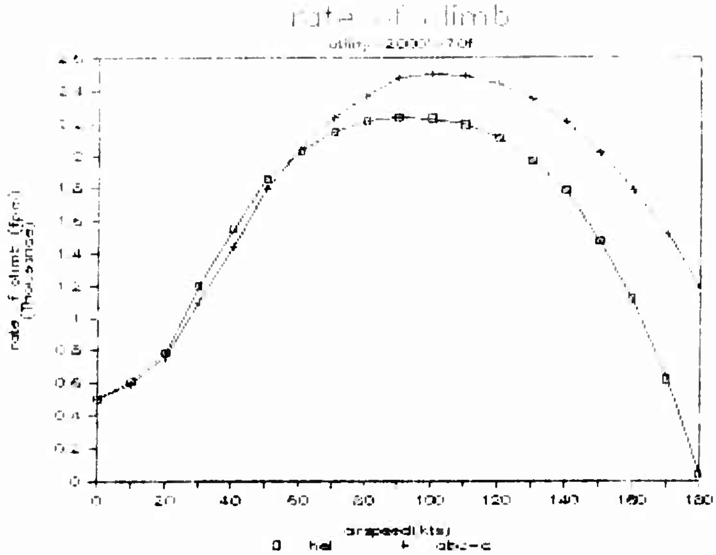

Figure N-V-172. Utility climb rate: helicopter and ABC-compound, 2,000 ft, 70°F.

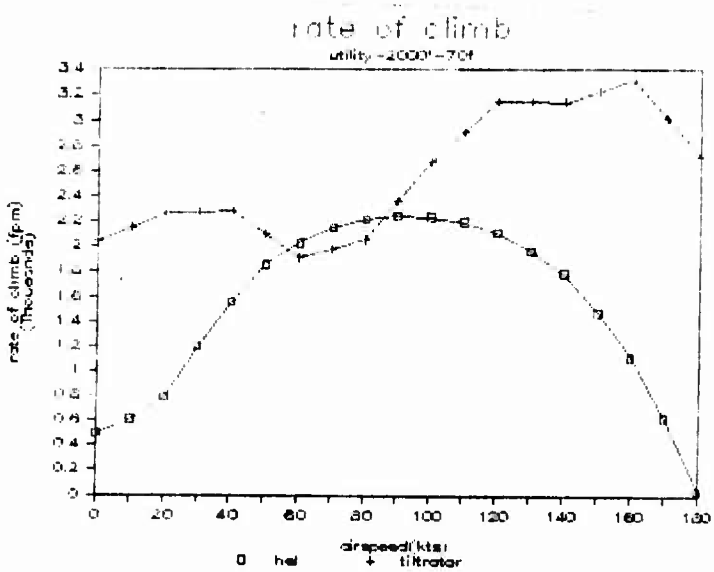

Figure N-V-173. Utility climb rate: helicopter and tilt rotor, 2,000 ft, 70°F.

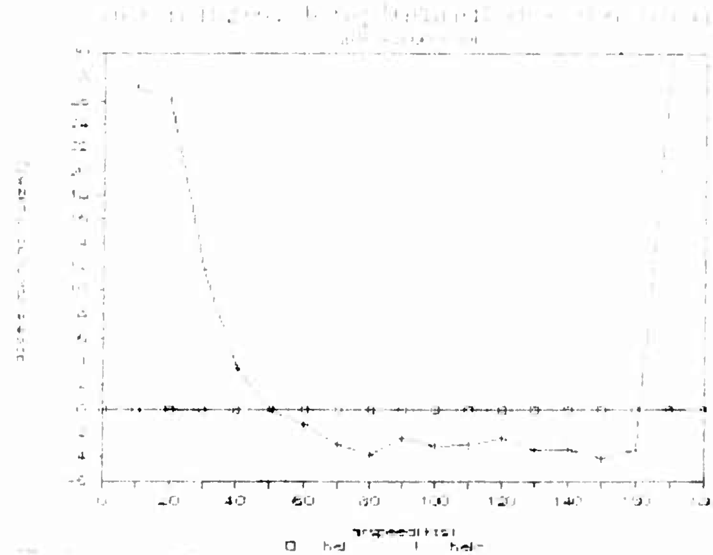

Figure N-V-174. Utility normalized longitudinal acceleration: helicopter and helicopter-compound, 2,000 ft, 70°F.

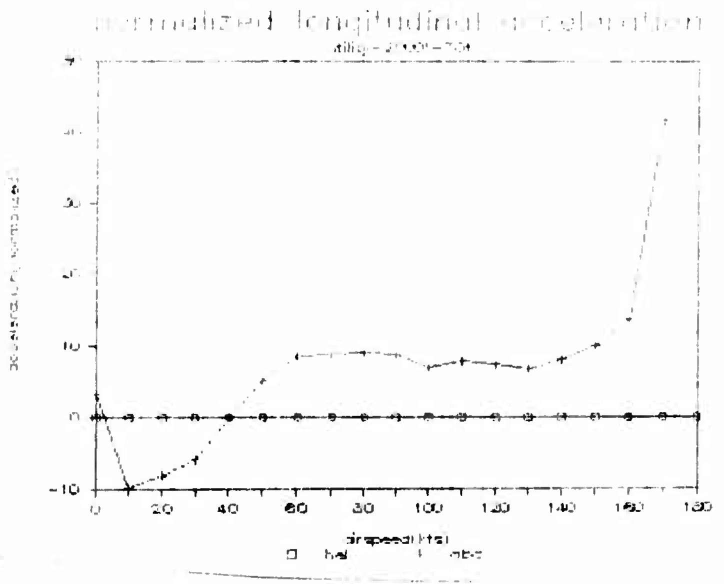

Figure N-V-175. Utility normalized longitudinal acceleration: helicopter and ABC, 2,000 ft, 70°F.

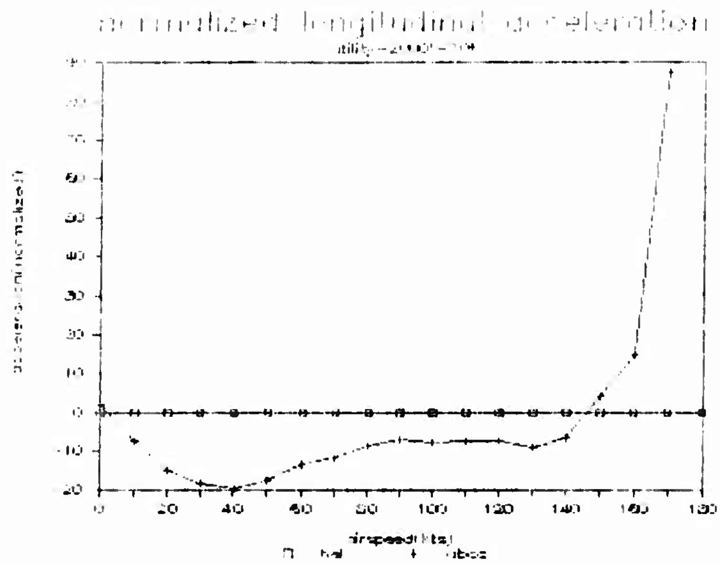

Figure N-V-176. Utility normalized longitudinal acceleration: helicopter and ABC-compound, 2,000 ft, 70°F.

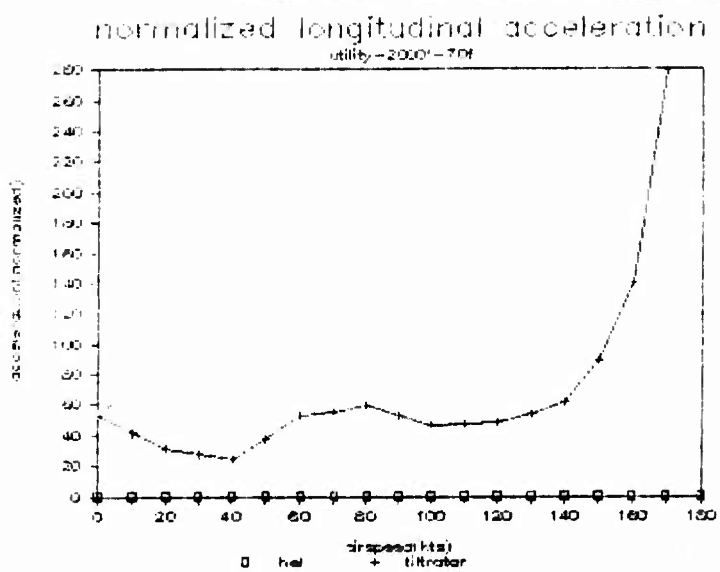

Figure N-V-177. Utility normalized longitudinal acceleration: helicopter and tilt rotor, 2,000 ft, 70°F.

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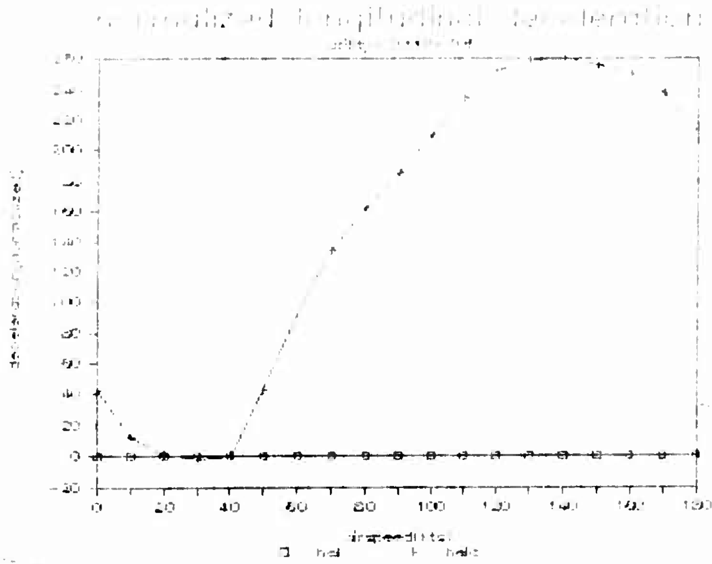

Figure N-V-178. Utility normalized longitudinal deceleration: helicopter and helicopter-compound, 2,000 ft, 70°F.

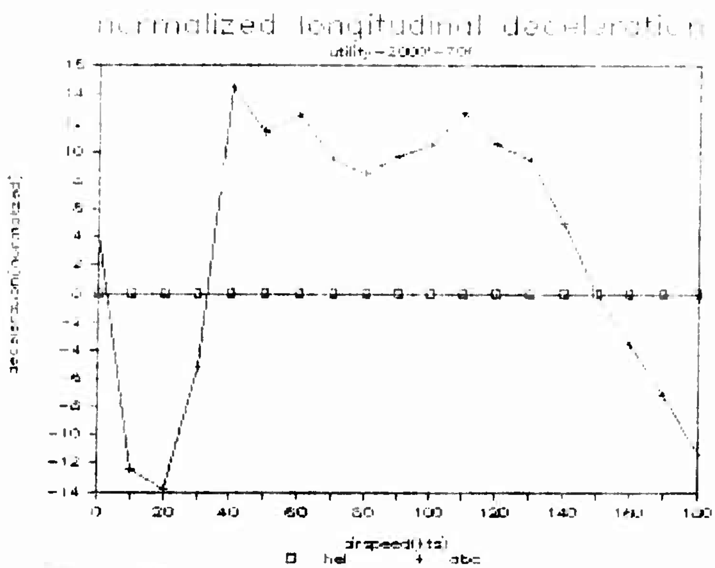

Figure N-V-179. Utility normalized longitudinal deceleration: helicopter and ABC, 2,000 ft, 70°F.

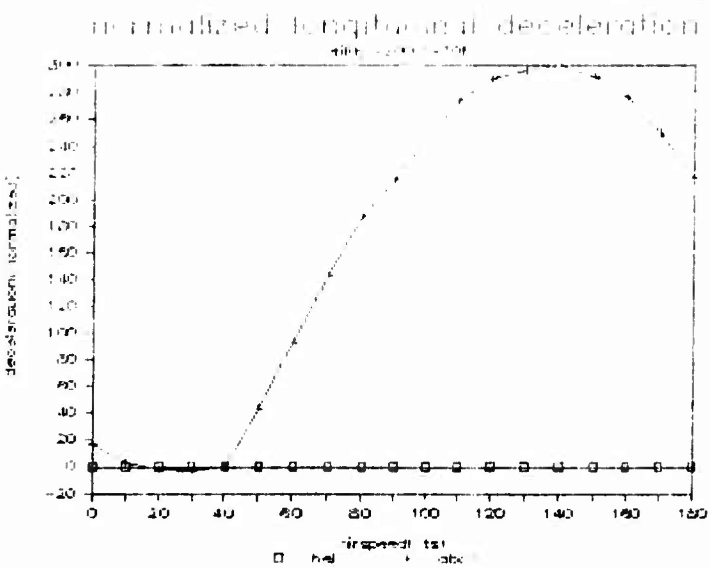

Figure N-V-180. Utility normalized longitudinal deceleration: helicopter and ABC-compound, 2,000 ft, 70°F.

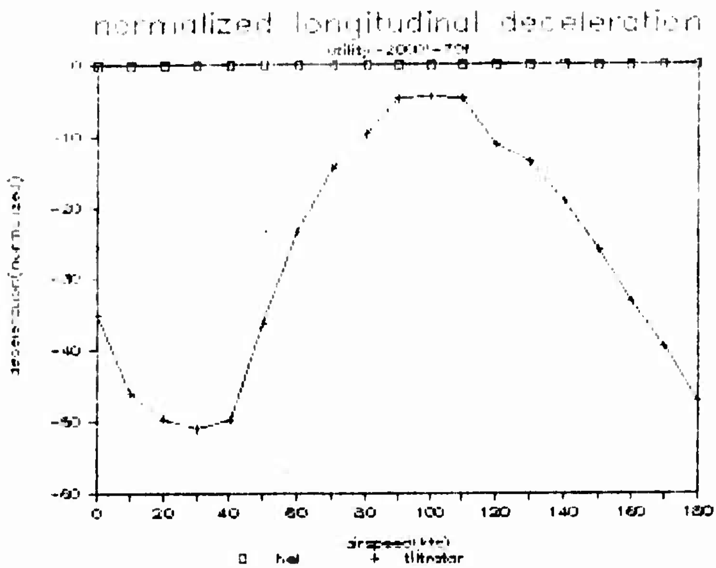

Figure N-V-181. Utility normalized longitudinal deceleration: helicopter and tilt rotor, 2,000 ft, 70°F.

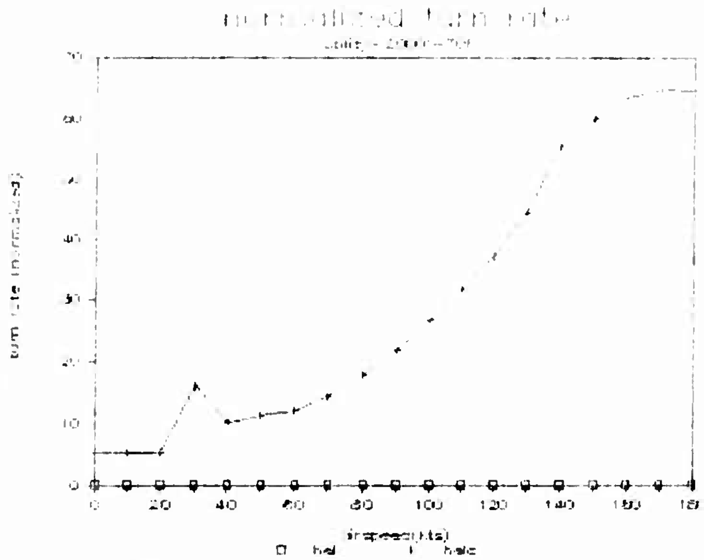

Figure N-V-182. Utility normalized turn rate: helicopter and helicopter-compound, 2,000 ft, 70°F.

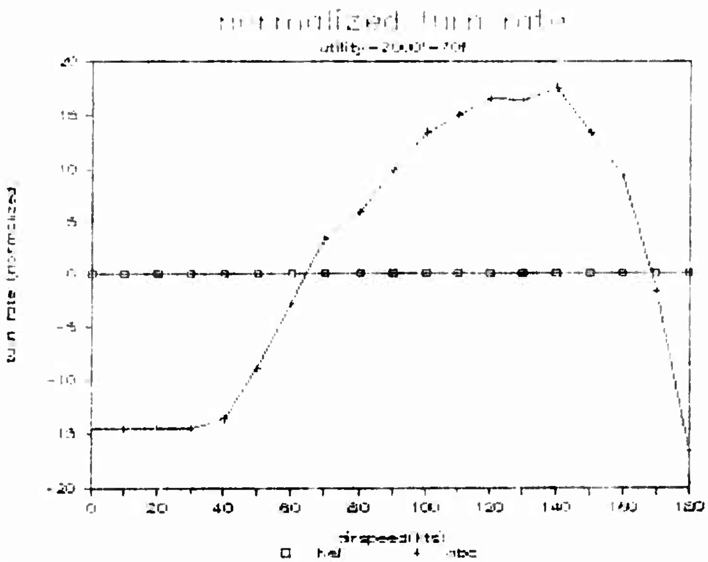

Figure N-V-183. Utility normalized turn rate: helicopter and ABC, 2,000 ft, 70°F.

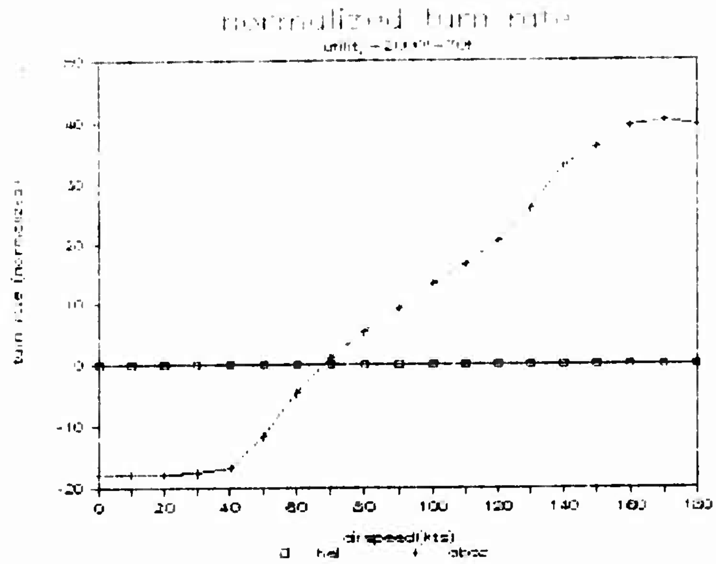

Figure N-V-184. Utility normalized turn rate: helicopter and ABC-compound, 2,000 ft, 70°F.

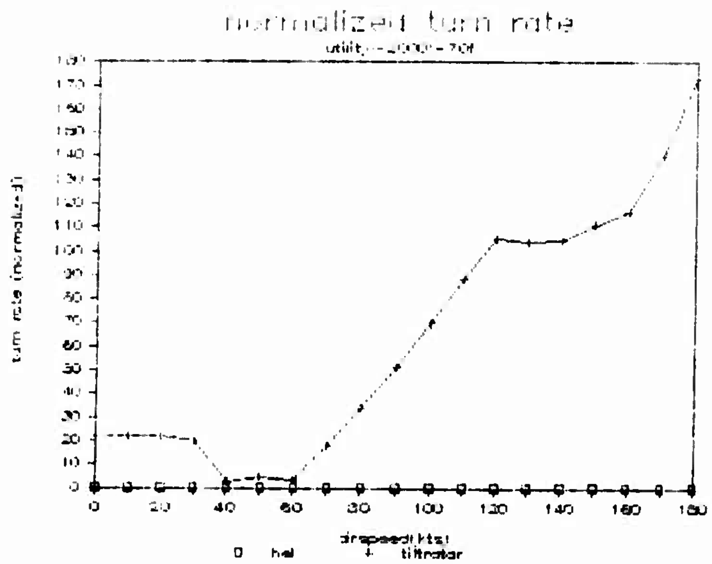

Figure N-V-185. Utility normalized turn rate: helicopter and tilt rotor, 2,000 ft, 70°F.

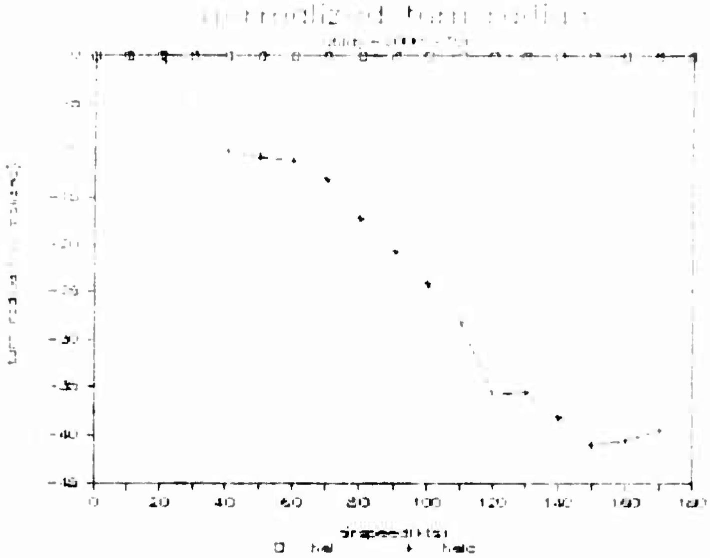

Figure N-V-186. Utility normalized turn radius: helicopter and helicopter-compound, 2,000 ft, 70°F.

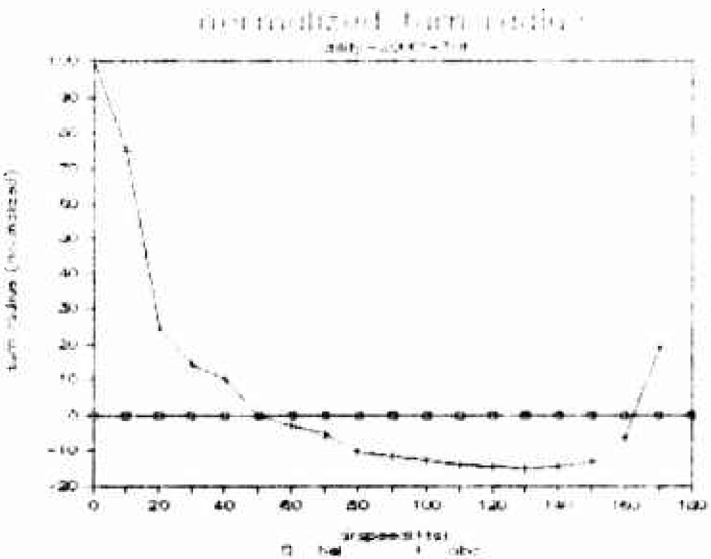

Figure N-V-187. Utility normalized turn radius: helicopter and ABC, 2,000 ft, 70°F.

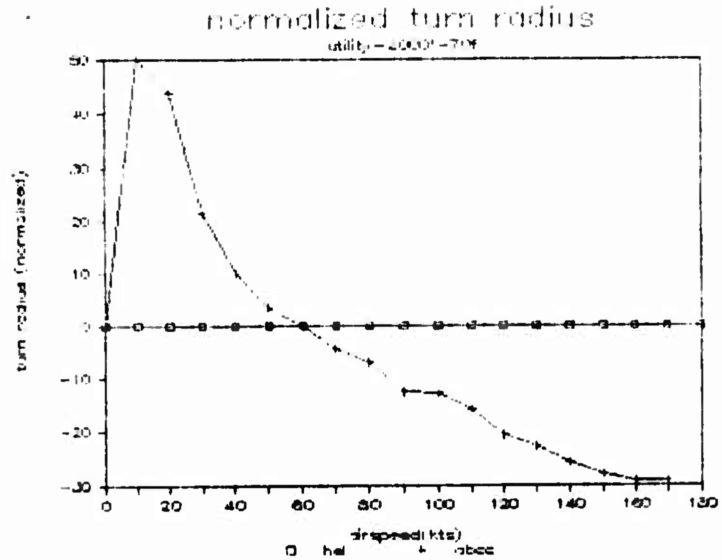

Figure N-V-188. Utility normalized turn radius: helicopter and ABC-compound, 2,000 ft, 70°F.

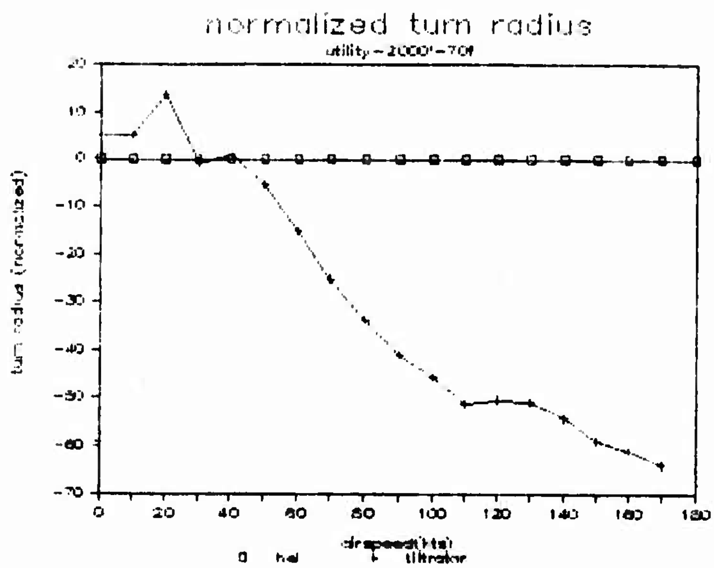

Figure N-V-189. Utility normalized turn radius: helicopter and tilt rotor, 2,000 ft, 70°F.

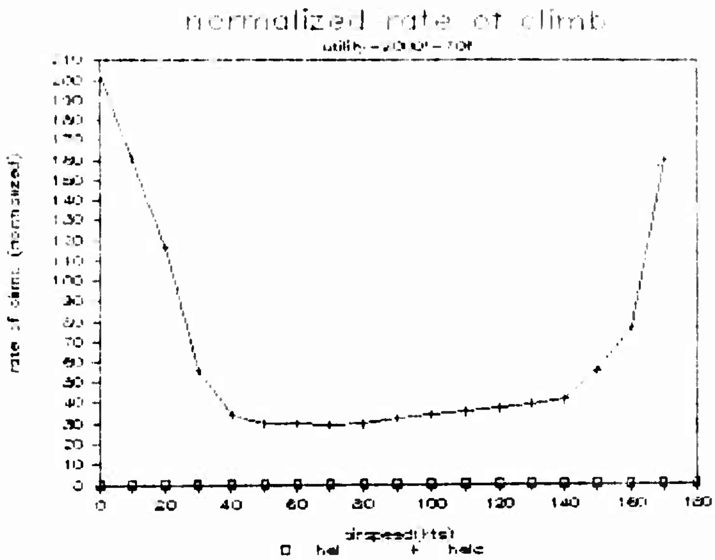

Figure N-V-190. Utility normalized climb rate: helicopter and helicopter-compound, 2,000 ft, 70°F.

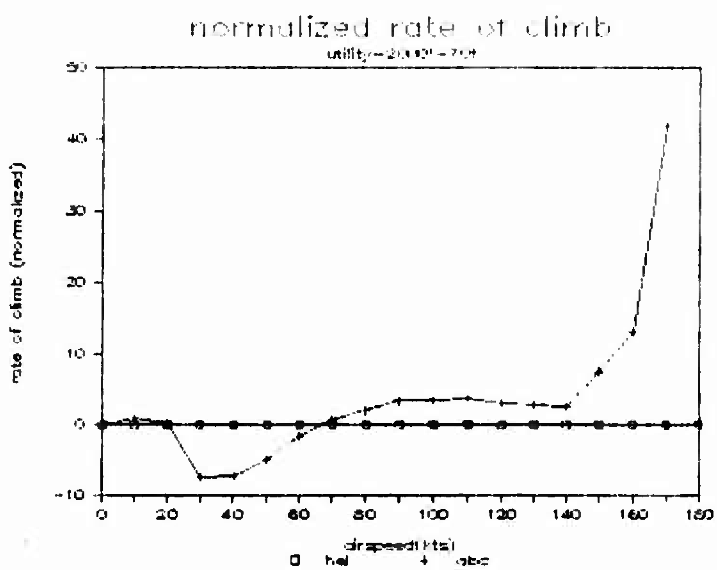

Figure N-V-191. Utility normalized climb rate: helicopter and ABC, 2,000 ft, 70°F.

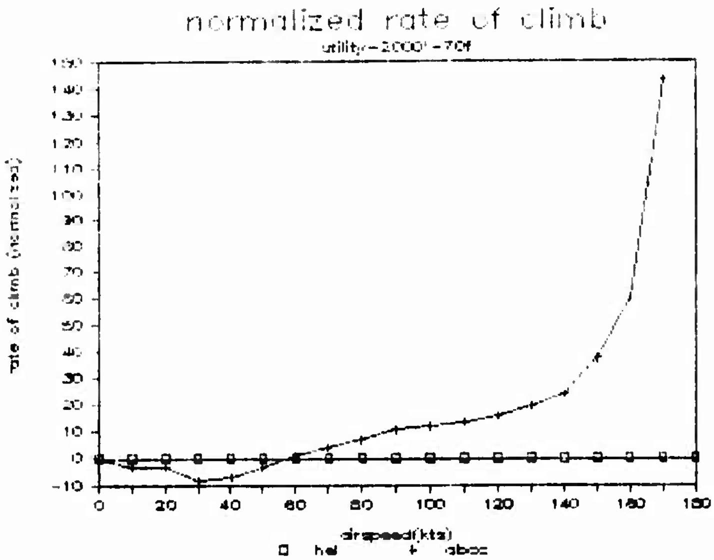

Figure N-V-192. Utility normalized climb rate: helicopter and ABC-compound, 2,000 ft, 70°F.

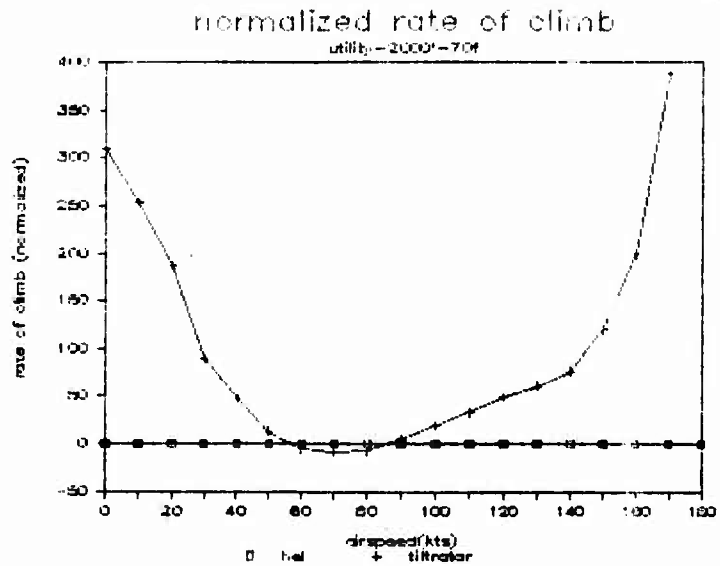

Figure N-V-193. Utility normalized climb rate: helicopter and tilt rotor, 2,000 ft, 70°F.

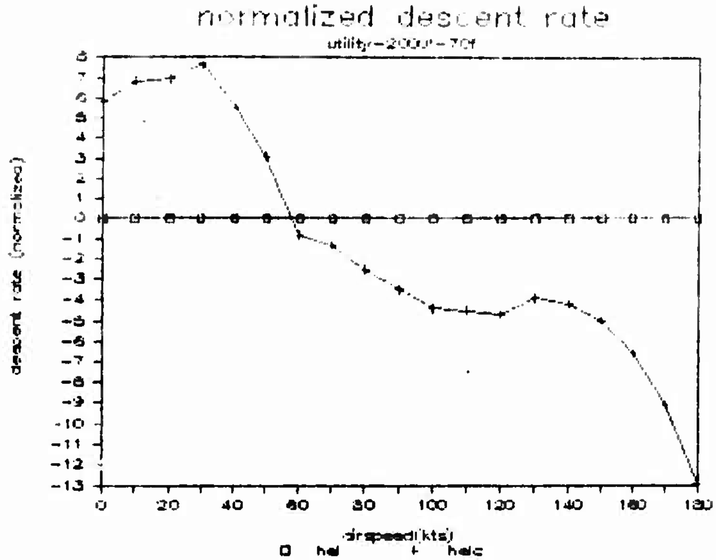

Figure N-V-194. Utility normalized descent rate: helicopter and helicopter-compound, 2,000 ft, 70°F.

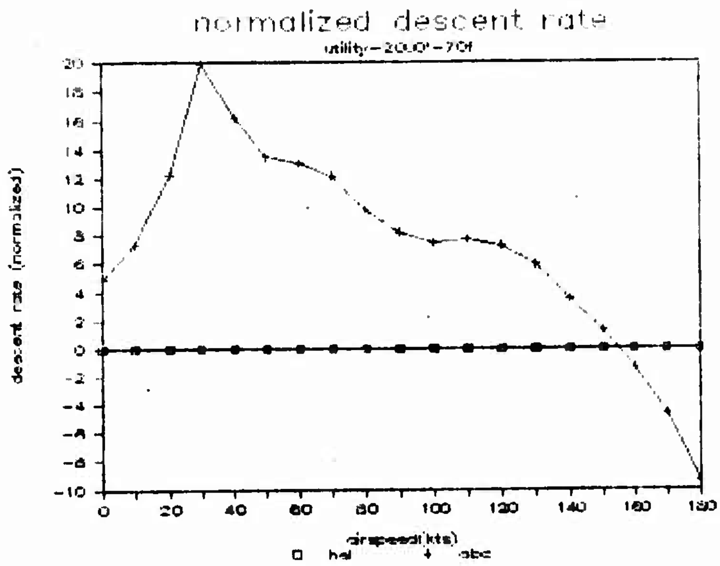

Figure N-V-195. Utility normalized descent rate: helicopter and ABC, 2,000 ft, 70°F.

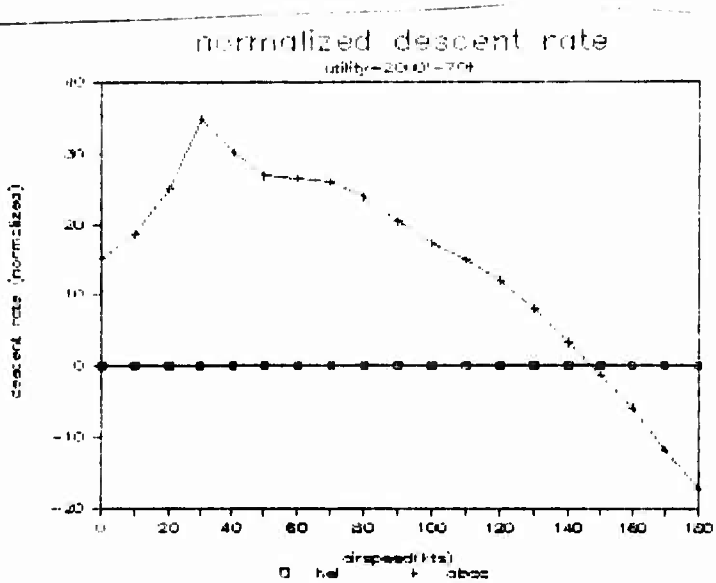

Figure N-V-196. Utility normalized descent rate: helicopter and ABC-compound, 2,000 ft, 70°F.

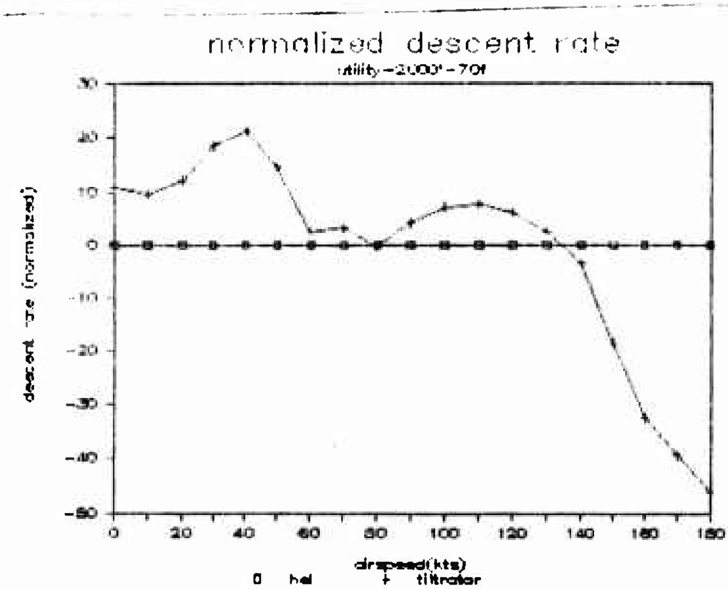

Figure N-V-197. Utility normalized descent rate: helicopter and tilt rotor, 2,000 ft, 70°F.

N-V-6. FINDINGS/CONCLUSIONS.

a. Findings.

(1) The helicopter is the preferred system in the 0-40 kt true airspeed (KTAS) and 40-120 KTAS interval.

(2) The TR is the preferred system in the above 120 KTAS interval.

(3) Considering the level of technology of the rotorcraft designs, it may be that all systems possess acceptable levels of M/A.

b. Conclusions.

(1) The opportunity to capitalize on and develop new technology suggests that both a helicopter and a tilt rotor should be selected for competitive flight tests so as to establish low speed (0-120 KTAS) flight dynamics comparisons.

(2) If a dissimilar fly-off is not permissible, then the helicopter would be the general overall preferred system considering criticality of terminal area operations (low speed, confined areas) because of the helicopter's vertical flight and handling quality characteristics, plus the weight growth margin and cost.

ANNEX VI TO APPENDIX N

LEVEL FLIGHT ANALYSIS-SPEED

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ANNEX VI TO APPENDIX N

LEVEL FLIGHT ANALYSIS-SPEED

N-VI-1. PURPOSE. This section of the level flight analysis will examine the inherent speed capabilities of each Light Helicopter Family (LHX) candidate relative to each other and how these speed differences impact on productivity.

N-VI-2. BACKGROUND. A central issue of the LHX is the need for speed. The merits of speed in the overall context of mission productivity, survivability, and deployability will be determined on the basis of results obtained from computer simulations of mission profiles with threat overlays.

N-VI-3. ASSUMPTION.

a. AirLand Battle and Army 21 concepts will mature to doctrine.

b. The modeled threat is representative of that in the 1995 time frame.

N-VI-4. LIMITATIONS.

a. This portion of the speed analysis will not address the need for speed but rather the variations of speed classifications for each LHX candidate.

b. The classifications that are analyzed are best range, intermediate rated power (IRP), maximum continuous power (MCP), and best endurance speed.

c. The analysis covers both Scout-Attack (SCAT) and Utility designs.

d. Ambient conditions are 4,000 feet (ft)/95° Fahrenheit (F) and 2,000 ft/70°F.

N-VI-5. METHODOLOGY.

a. The analysis is conducted using the new design helicopter as the benchmark against which all other designs will be compared. The analysis consists of identifying the difference in speed of the designs relative to the helicopter, establishing the percentage difference, and then relating the difference to the differential cost of the two. Comparisons are made relative to mission design gross weight (MDGW). The analysis covers both SCAT and Utility designs at 4,000 ft/95°F and 2,000 ft/70°F.

b. The second part of the analysis applies the speed differences to productivity measures in an attempt to identify the benefits of increased speed. The analysis was configuration dependent; that is, speed was not an independent variable in the analysis. Speed was not isolated from its configuration,

rather it was viewed as a capability inherent in the configuration type. Thus, this effort is better termed a configuration analysis rather than an isolated speed analysis.

c. The helicopter mission survivability (HELMS) model run at Waterways Experiment Station, Vicksburg, Mississippi, provided the framework for the analysis. Eight of the forty-eight mission profiles were chosen by the study team as representative of the remaining forty and were used during this analysis. Flight routes were chosen by active duty aviators and were then exercised in HELMS. For the purposes of this effort, boundary conditions were established to isolate configuration differences over the predetermined flight routes. The boundaries were speed and altitude. Run matrices were designed to isolate those variables which were under study. In this case, the variables were mission completion time, exposure time, and average height above the ground.

d. The analysis was conducted with two altitude bands and one speed band: altitudes of 0-150 ft and 0-25 ft and airspeeds of 0 to IRP speed (see paragraph N-VI-6d). This method allowed the model to exercise the performance capabilities of each configuration and to fly the aircraft as fast as possible within the altitude band specified. With these bands, a matrix was established from which the analysis was conducted. An example matrix is at figure N-VI-1. This matrix allows comparison among configurations as well as isolating the relationship between airspeed and altitude. This matrix was used for each of the eight missions.

Speed 0- IRP					
Helicopter	Tilt Rotor (TR)	Advancing Blade Concept (ABC)	ABC-Compound	Helicopter Compound	A129
0-150 ft X	X	X	X	X	X
0-25 ft X	X	X	X	X	X

Figure N-VI-1. HELMS run matrix.

e. The outputs of HELMS used in this portion of the analysis were mission completion time and distance and total exposure time and distance. These outputs were subjected to an analysis of variance which is a method of estimating how much of the total variation in a set of data can be attributed to certain assignable causes of variation and how much can be attributed to chance.

There are two assignable causes of variation in this experiment, configuration and altitude. The results of this test isolate the configuration differences to those which are statistically significant.

f. The final step in this analysis was the combining of mission profile prioritizations with the statistically significant configuration differences, producing a measure of productivity. This process provides a final common basis upon which an equitable configuration comparison can be made.

N-VI-6. RESULTS/ANALYSIS.

a. Best Endurance Speed.

(1) The best endurance speed, V(BE), discussed herein is defined as the speed corresponding to minimum power required and hence, minimum fuel flow. In general, but not exclusively, it is associated with a loiter condition. The comparisons between the different designs are presented in figure N-VI-2. Inspection of the figure reveals that the helicopter has the lowest (except for one case) value of all the designs. Alternatively, the TR has the highest value; however, by judiciously varying the rotor nacelle incidence angle, the TR can fly at 90 knots true air speed (KTAS) with essentially the same power setting that it requires at 140 KTAS. The "goodness" or preference of having a low endurance speed would be situation-dependent. However, the TR, with its ability to loiter in a speed interval of approximately 90 to 140 KTAS, is attractive from the perspective of being flexible. At the same time, the TR is postured to contend with an air threat; as it is essentially operating at its best specific excess power level.

(2) Data depicting the variation of best endurance speed as a function of gross weight at the different ambient conditions are presented in figures N-VI-3 through N-VI-6.

b. Best Range Speed (V(.99BR)).

(1) The V(.99BR) presented is defined as the higher of the two airspeeds which give nautical miles (nm) per pound (lb) of fuel equal to 99 percent of the maximum nm per lb of fuel at a given weight. It is noted that nm per lb of fuel is called specific range. The comparisons between the different designs are presented in figure N-VI-7. The data presented shows that V(.99BR) is configuration-dependent and that the helicopter has the lowest V(.99BR) which directly affects productivity because the LHX missions are heavily dependent on V(.99BR). Given the opportunity to use V(.99BR), the TR would essentially be in a different class than the other designs. V(.99BR) may also be referred to as long range cruise speed V(LRC).

(2) Data depicting the variation of V(.99BR) as a function of gross weight at the different ambient conditions are presented in figures N-VI-8 through N-VI-11.

Ambience	Type	Design	MDGW (lb)	V(BE) (KTAS)	Normalized
4,000 ft/95°F	SCAT	HEL*	9,097	89	1.00
		HEL-C*	10,335	100	1.12
		ABC	10,292	92	1.03
		ABC-C*	11,182	97	1.09
		TR	10,850	140	1.57
	Utility	HEL	9,747	92	1.00
		HEL-C	10,879	104	1.13
		ABC	10,954	93	1.01
		ABC-C	11,838	103	1.12
		TR	11,371	140	1.52
2,000 ft/70°F	SCAT	HEL	9,097	88	1.00
		HEL-C	10,335	90	1.02
		ABC	10,292	85	.97
		ABC-C	11,182	95	1.08
		TR	10,850	140	1.59
	Utility	HEL	9,747	87	1.00
		HEL-C	10,879	95	1.09
		ABC	10,954	88	1.01
		ABC-C	11,838	98	1.13
		TR	11,371	140	1.61

*HEL - helicopter
HEL-C - compound helicopter
ABC-C - compound ABC

Figure N-VI-2. Comparison of LHX best endurance speeds.

BEST ENDURANCE SPEED VS GROSS WEIGHT
4000 FT/95°F
LHX-SCAT

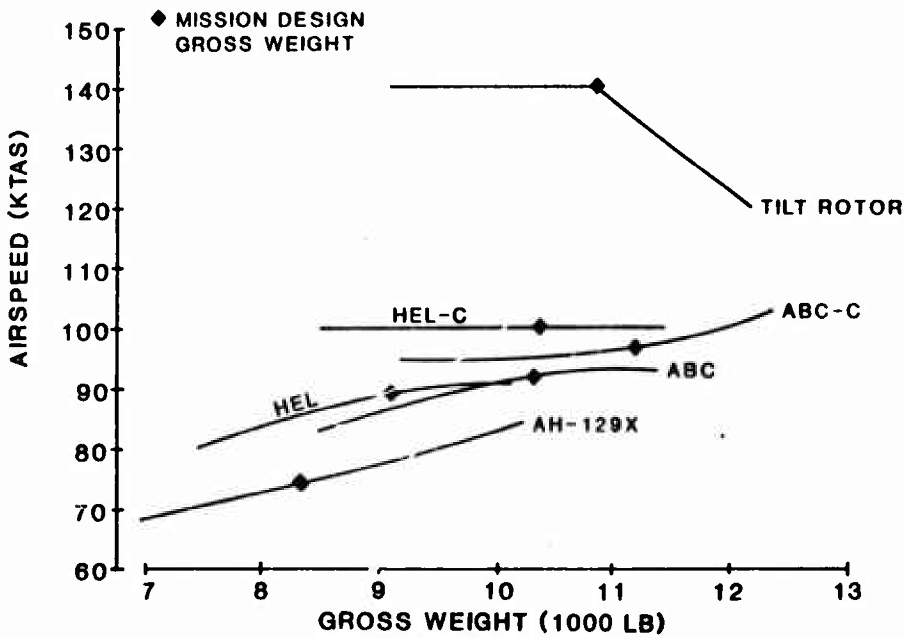

Figure N-VI-3. SCAT best endurance speed, 4,000'/95°F.

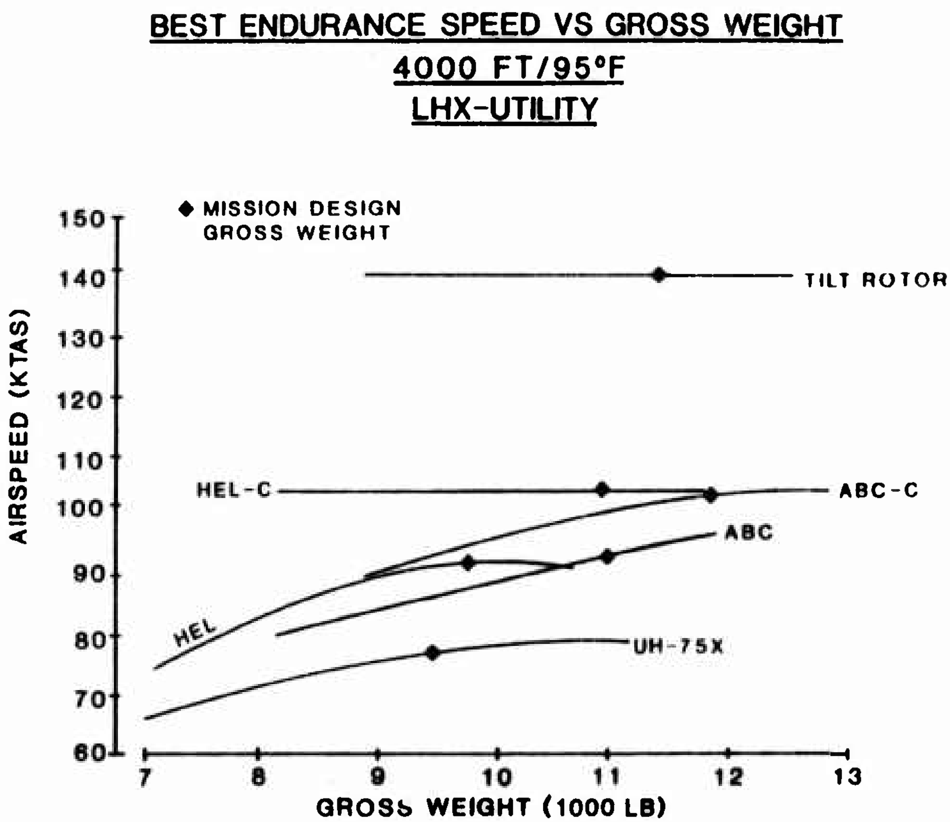

Figure N-VI-4. Utility best endurance speed, 4,000'/95°F.

BEST ENDURANCE SPEED VS GROSS WEIGHT
2000 FT/70° F
LHX-SCAT

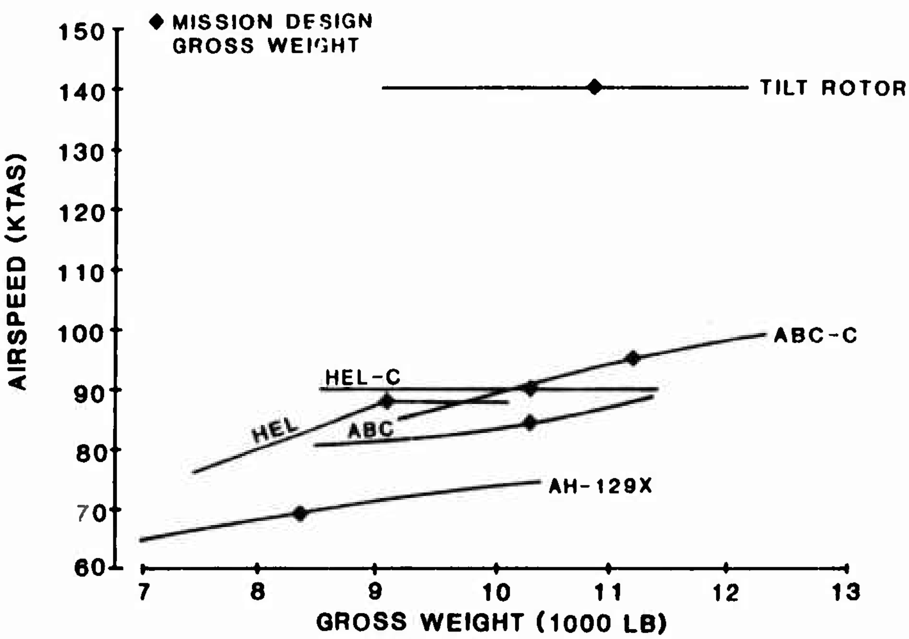

Figure N-VI-5. SCAT best endurance speed, 2,000'/70°F.

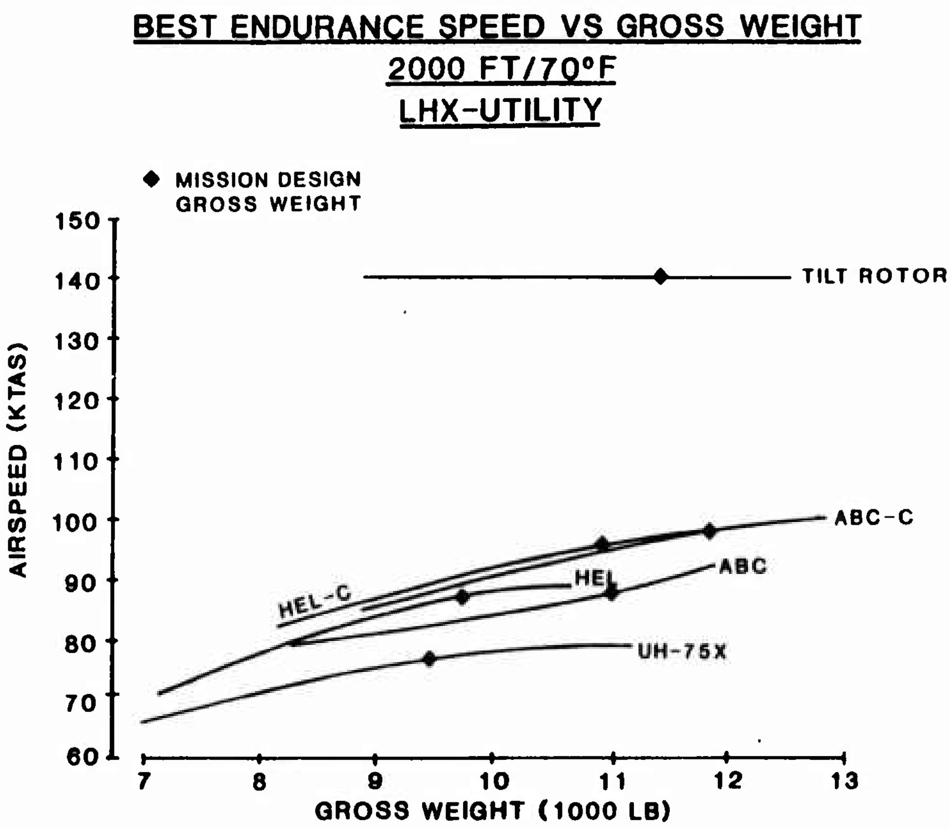

Figure N-VI-6. Utility best endurance speed, 2,000'/70°F.

Ambience	Type	Design	MDGW (lb)	V(.99BR) (KTAS)	Normalized
4,000 ft/95°F	SCAT	HEL	9,097	135	1.00
		HEL-C	10,335	158	1.17
		ABC	10,292	145	1.07
		ABC-C	11,182	158	1.17
		TR	10,850	216	1.60
	Utility	HEL	9,747	136	1.00
		HEL-C	10,879	158	1.16
		ABC	10,954	146	1.07
		ABC-C	11,838	158	1.16
		TR	11,371	205	1.51
2,000 ft/70°F	SCAT	HEL	9,097	130	1.00
		HEL-C	10,335	148	1.14
		ABC	10,292	140	1.08
		ABC-C	11,182	152	1.17
		TR	10,850	214	1.65
	Utility	HEL	9,747	132	1.00
		HEL-C	10,879	146	1.11
		ABC	10,954	138	1.05
		ABC-C	11,838	153	1.16
		TR	11,371	199	1.51

Figure N-VI-7. Comparison of LHX best range speeds.

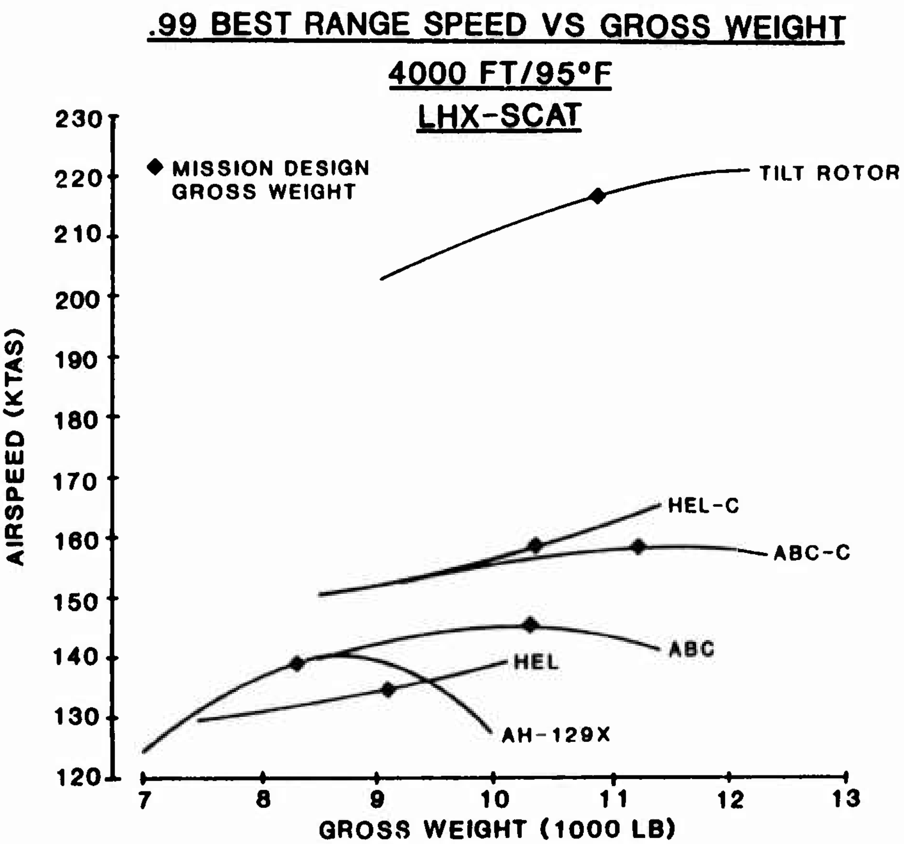

Figure N-VI-8. SCAT .99 best specific range speed, 4,000'/95°F.

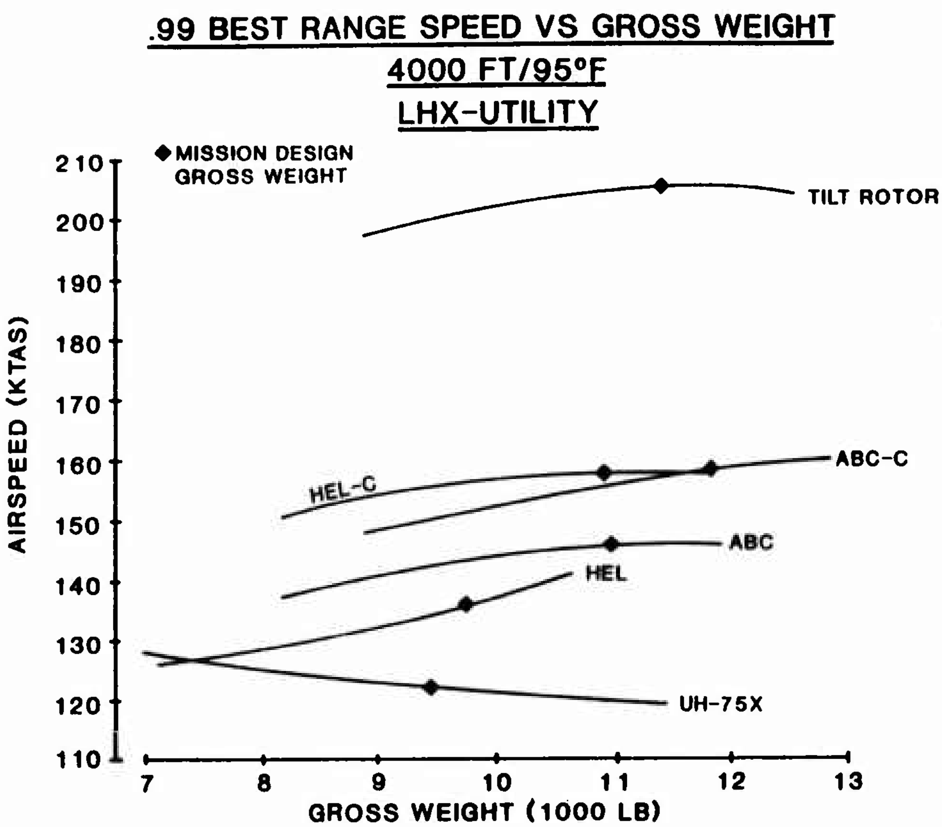

Figure N-VI-9. Utility .99 best specific range speed, 4,000'/95°F.

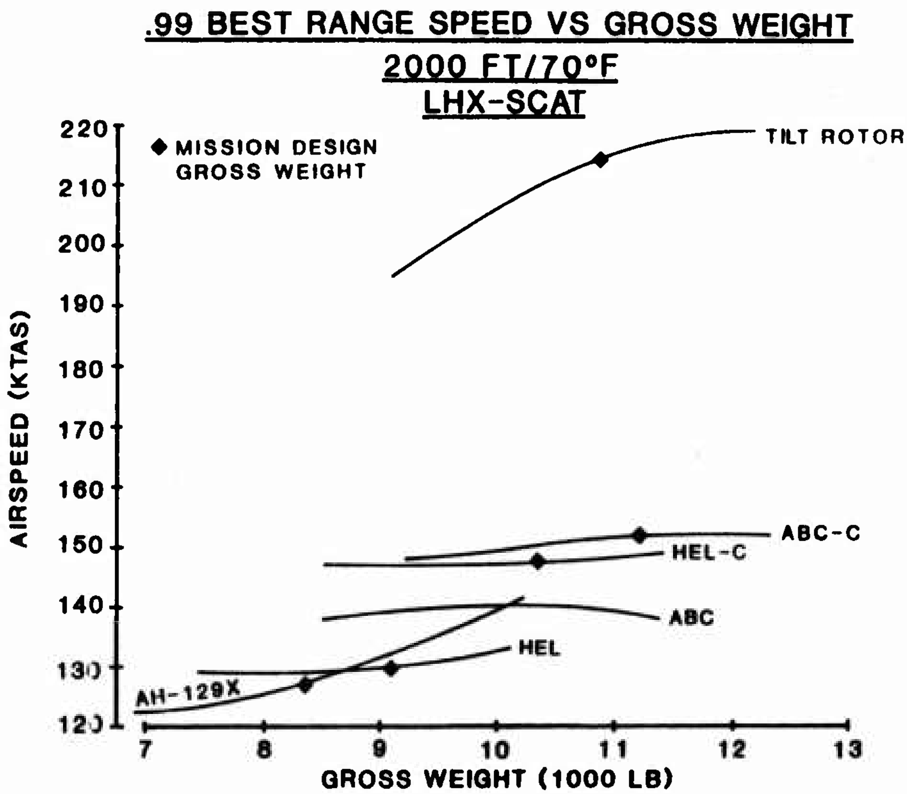

Figure N-VI-10. SCAT .99 best specific range speed, 2,000'/70°F.

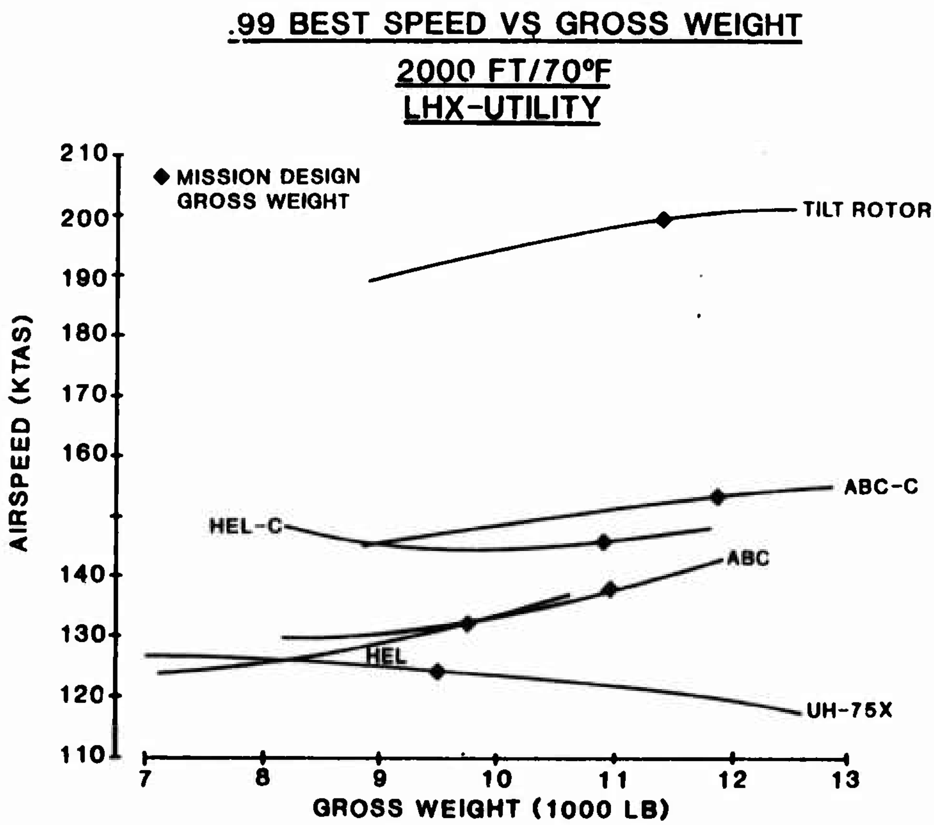

Figure N-VI-11. Utility .99 best specific range speed, 2,000'/70°F.

c. Maximum Continuous Speed (V(MCP)).

(1) V(MCP) is defined as the highest speed that can be maintained without an engine time limitation when operating the engine at MCP. As in the other speed categories, the capability is also dependent on gross weight/drag, altitude, and temperature. Figure N-VI-12 is a summary of V(MCP) for the LHX configurations. The information presented shows two separate classes of speed: the TR and all the other types.

(2) Figures N-VI-13 through N-VI-16 present the variation in V(MCP) over the range of operating gross weights for each configuration. Inspection of the data shows the distinct separation of capability between the TR and other configurations.

d. Intermediate Rated Power Speed (V(IRP)) (Dash Speed).

(1) V(IRP) is the speed which has been referred to as dash speed V(DASH) during the LHX effort and is the highest speed attainable at a given gross weight/drag, altitude, and temperature at the specified power setting. Unless otherwise specified by the engine manufacturer, the time limitation on the engine operating at this level is 30 minutes. However, after a (short) period of time at a less power setting, V(IRP) may be used again. The exact specification would be defined by the engine manufacturer. Figure N-VI-17 is a summary of V(IRP) capabilities of the LHX configurations. The data again highlights the different levels of capability between the TR and the other LHX configurations.

Ambience	Type	Design	MDGW (lb)	V(DASH) (KTAS)	Normalized
4,000 ft/95°F	SCAT	HEL	9,097	164	1.00
		HEL-C	10,335	185	1.13
		ABC	10,292	171	1.04
		ABC-C	11,182	186	1.13
		TR	10,850	245	1.49
	Utility	HEL	9,747	164	1.00
		HEL-C	10,879	184	1.12
		ABC	10,954	168	1.02
		ABC-C	11,838	184	1.12
		TR	11,371	244	1.49
2,000 ft/70°F	SCAT	HEL	9,097	175	1.00
		HEL-C	10,335	192	1.10
		ABC	10,292	184	1.05
		ABC-C	11,182	199	1.14
		TR	10,850	243	1.39
	Utility	HEL	9,747	171	1.00
		HEL-C	10,879	191	1.12
		ABC	10,954	181	1.06
		ABC-C	11,838	198	1.16
		TR	11,371	243	1.42

Figure N-VI-12. Comparison of LHX MCP speeds.

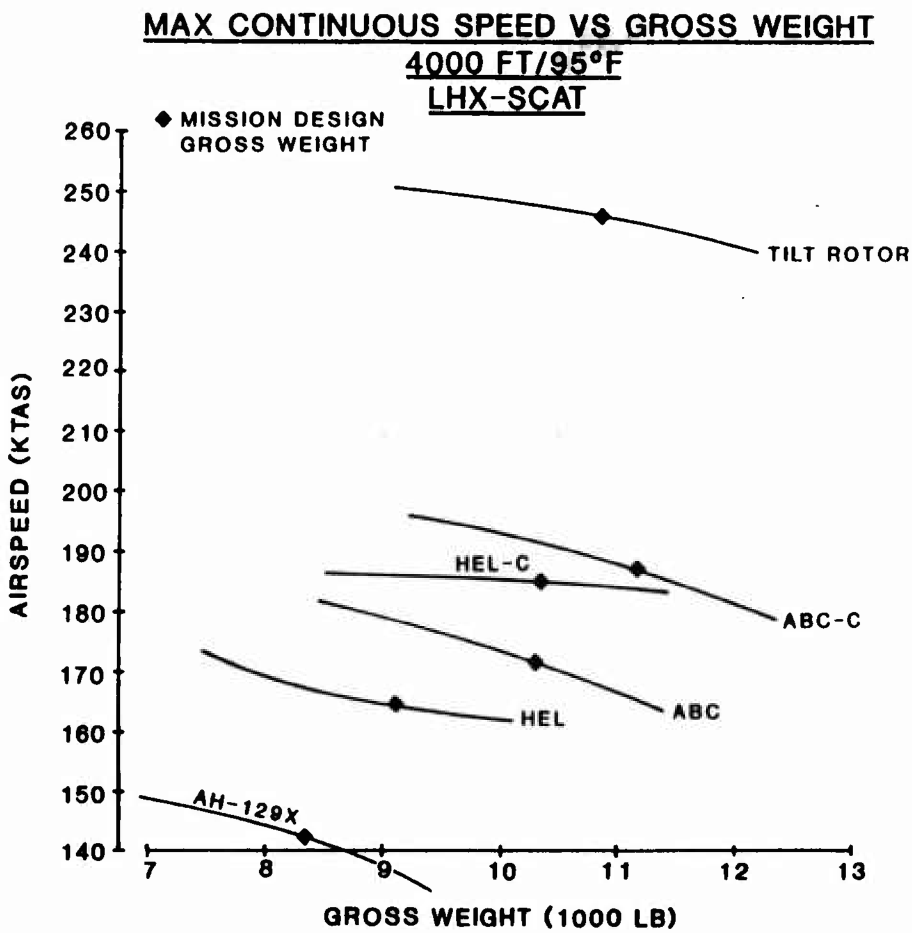

Figure N-VI-13. SCAT maximum continuous power speed, 4,000'/95°F.

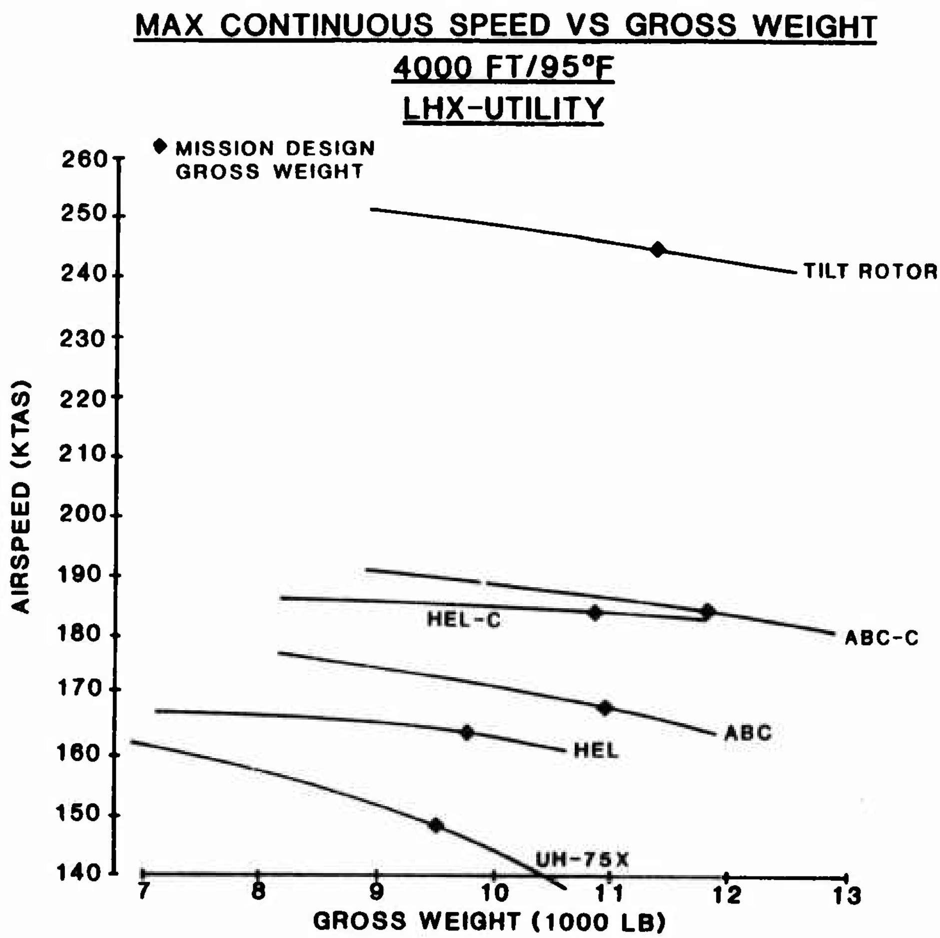

Figure N-VI-14. Utility maximum continuous power speed, 4,000'/95°F.

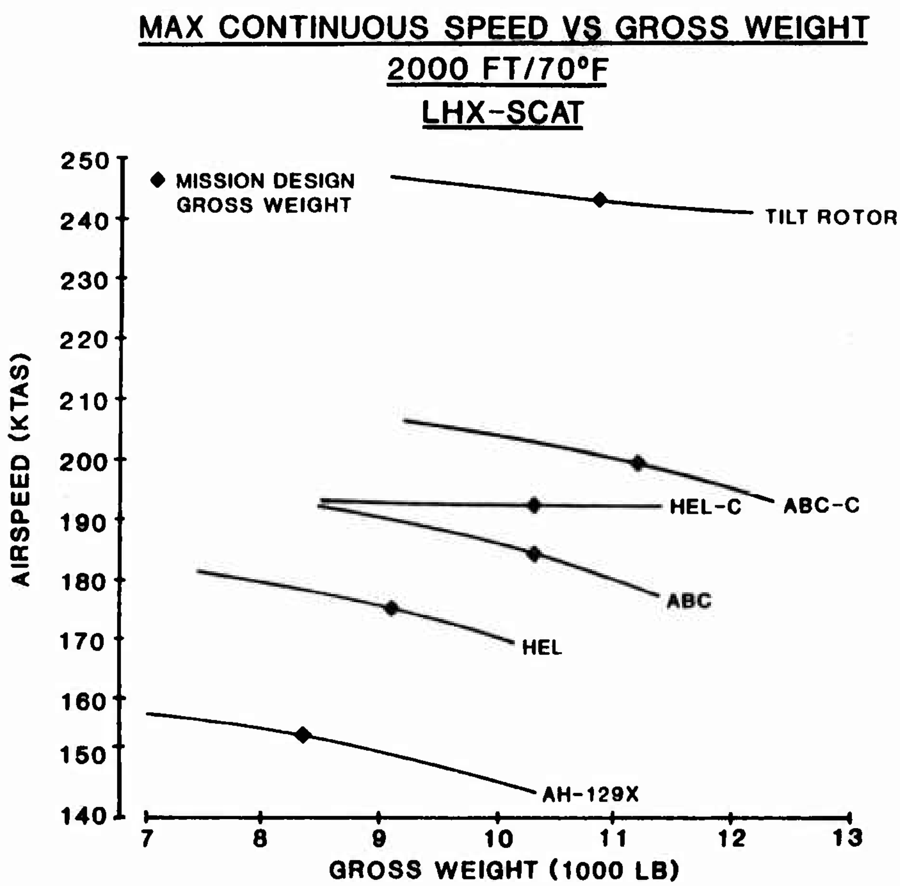

Figure N-VI-15. SCAT maximum continuous power speed, 2,000'/70°F.

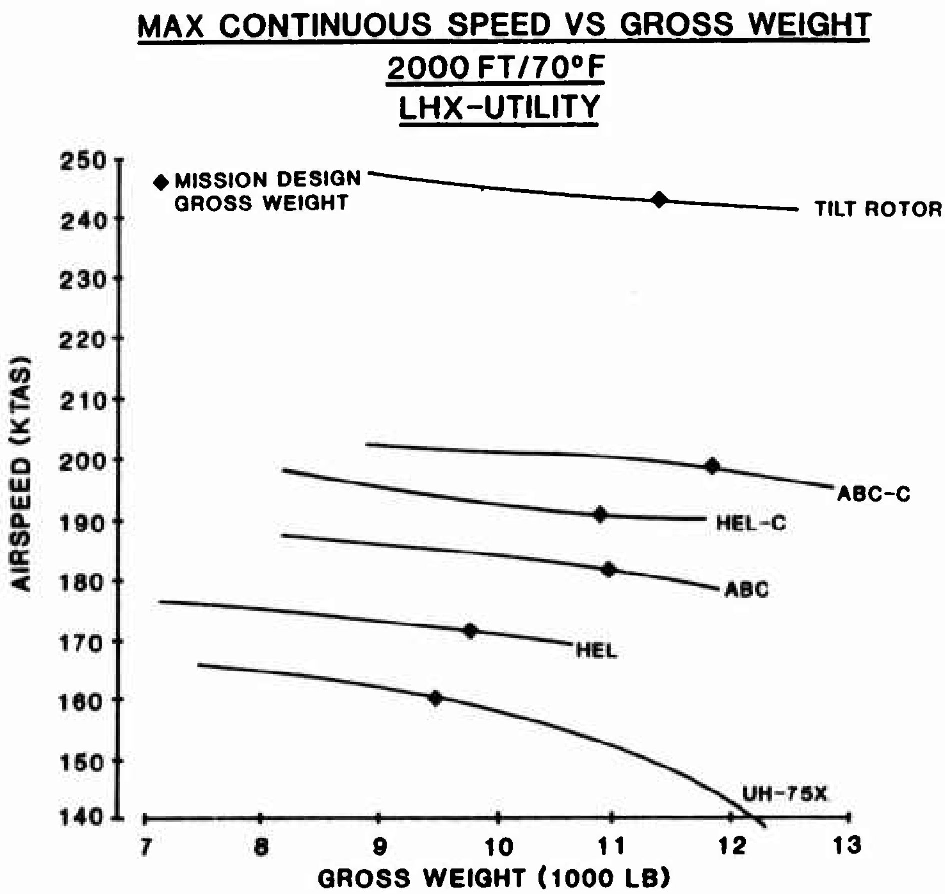

Figure N-VI-16. Utility maximum continuous power speed, 2,000'/70°F.

3UV

Ambient	Type	Design	MDGW (lb)	V(DASH) (KTAS)	Normalized
4,000 ft/95°F	SCAT	HEL	9,097	181	1.00
		HEL-C	10,335	200	1.10
		ABC	10,292	187	1.03
		ABC-C	11,182	204	1.13
		TR	10,850	252	1.39
	Utility	HEL	9,747	176	1.00
		HEL-C	10,879	199	1.13
		ABC	10,954	184	1.05
		ABC-C	11,838	202	1.15
		TR	11,371	252	1.43
2,000 ft/70°F	SCAT	HEL	9,097	188	1.00
		HEL-C	10,335	204	1.09
		ABC	10,292	195	1.04
		ABC-C	11,182	210	1.12
		TR	10,850	243	1.29
	Utility	HEL	9,747	184	1.00
		HEL-C	10,879	203	1.10
		ABC	10,954	192	1.04
		ABC-C	11,838	208	1.13
		TR	11,371	243	1.32

Figure N-VI-17. Comparison of LHX IRP speeds.

(2) Figures N-VI-18 through N-VI-21 present the complete range of operating gross weight and V(IRP) relationships for the LHX configurations and further illustrate the large difference in capability level between the TR and the remaining LHX configurations.

e. Summary of Speed Capabilities. A method to evaluate the efficiency in converting horsepower into speed has been developed and is described herein and proffered. The method consists of taking each speed interval, i.e., V(BE), V(.99BR), V(MCP), and V(IRP) individually and for each configuration and calculating the ratio of velocity to total engine rated horsepower at sea level, standard temperature. These values were then normalized using the helicopter as the base value. The results are presented in figures N-VI-22 through N-VI-25. As can be seen from the figures, the compound helicopter, ABC, and compound ABC are consistently less efficient (apparently) in utilizing the horsepower while the TR is consistently better than the helicopter. It is emphasized that the analysis is for speeds from minimum power required through IRP.

f. HELMS Simulation Results. This section describes the results of the HELMS simulation for each of the five configurations. Figures N-VI-26 and N-VI-27 contain the basic flight path results for the 0-25 ft and 0-150 ft cases, respectively. The mission times for the 0-25 ft cases are slightly longer than those for the corresponding 0-150 ft cases. The longer the mission distance, the more significant the mission time difference. This is a result of being able to fly faster as the flight altitude is increased. This relationship can be seen in figure N-VI-28 which was derived from algorithms contained in the HACES model and was based upon empirical data. The differences in mission time are generally 1-3 percent longer for the 0-25 ft cases while the distances are generally the same as the 0-150 ft cases. The opposite relationship exists for exposure time and distance. The times and distances for the 0-25 ft cases are generally 10-15 percent shorter than those for the 0-150 ft cases. As with mission time, the exposure results are logical as the higher the flight altitude, the increased probability of clear line of sight.

g. Analysis of Variance (ANOVA). An analysis of variance (ANOVA) was conducted on four HELMS statistics, mission completion time, mission distance, total exposure time, and total exposure distance, to determine if there were any statistically significant differences among configurations and/or effects of flight altitudes. The ANOVA was designed to isolate the effects of the two treatments, flight altitude and configuration type, on the four statistics. To accomplish this, a null and alternative hypothesis were created to test the statistics: $H_o: \mu_1 = \mu_2$ and $H_a: \mu_1 \neq \mu_2$. If a statistically significant difference existed, the null hypothesis could be rejected, indicating a treatment effect; conversely, if there were no significant differences the null hypothesis could not be rejected indicating equal means and no treatment effect. The HELMS run matrix lent itself to this type of significance test and was conducted at the 0.05 significance level. The missions were flown

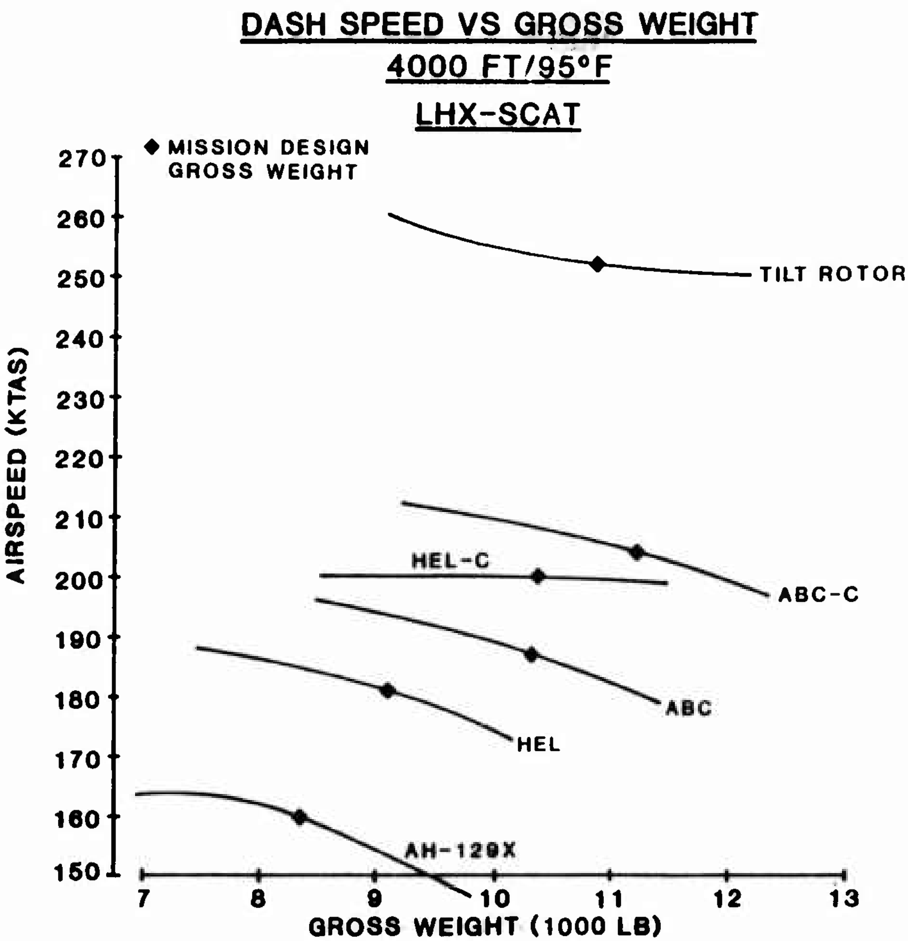

Figure N-VI-18. SCAT intermediate rated power speed, 4,000'/95°F.

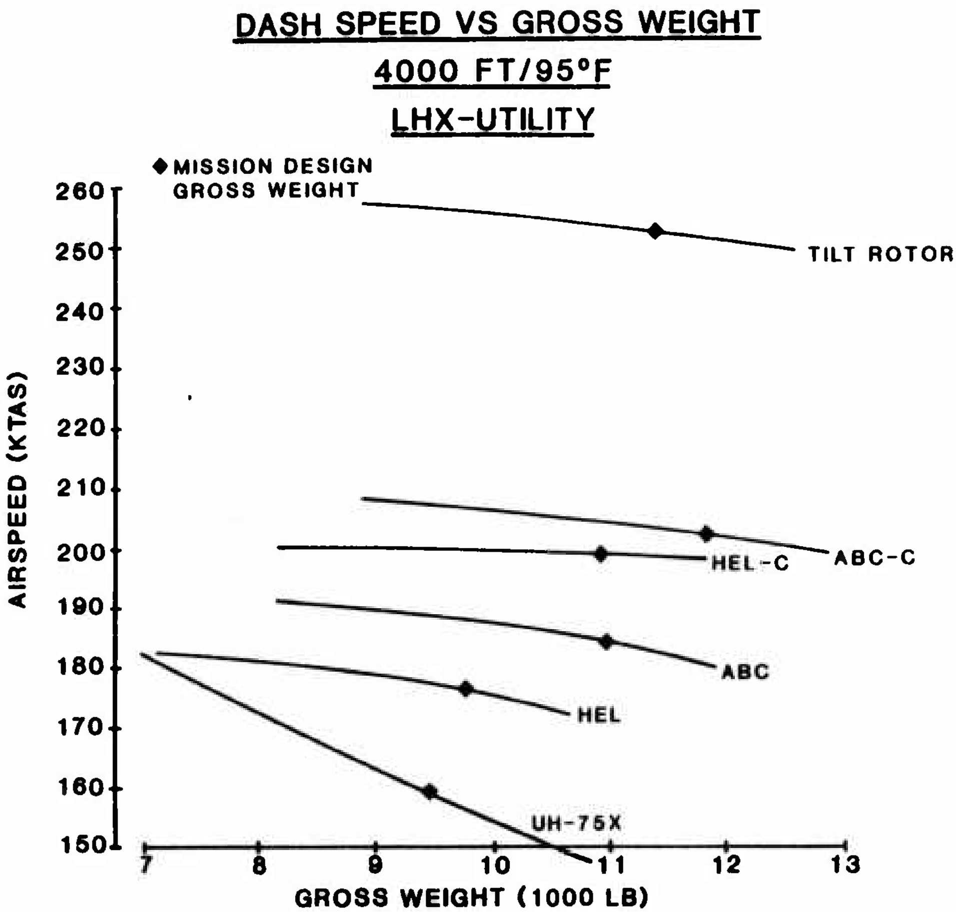

Figure N-VI-19. Utility intermediate rated power speed, 4,000'/95°F.

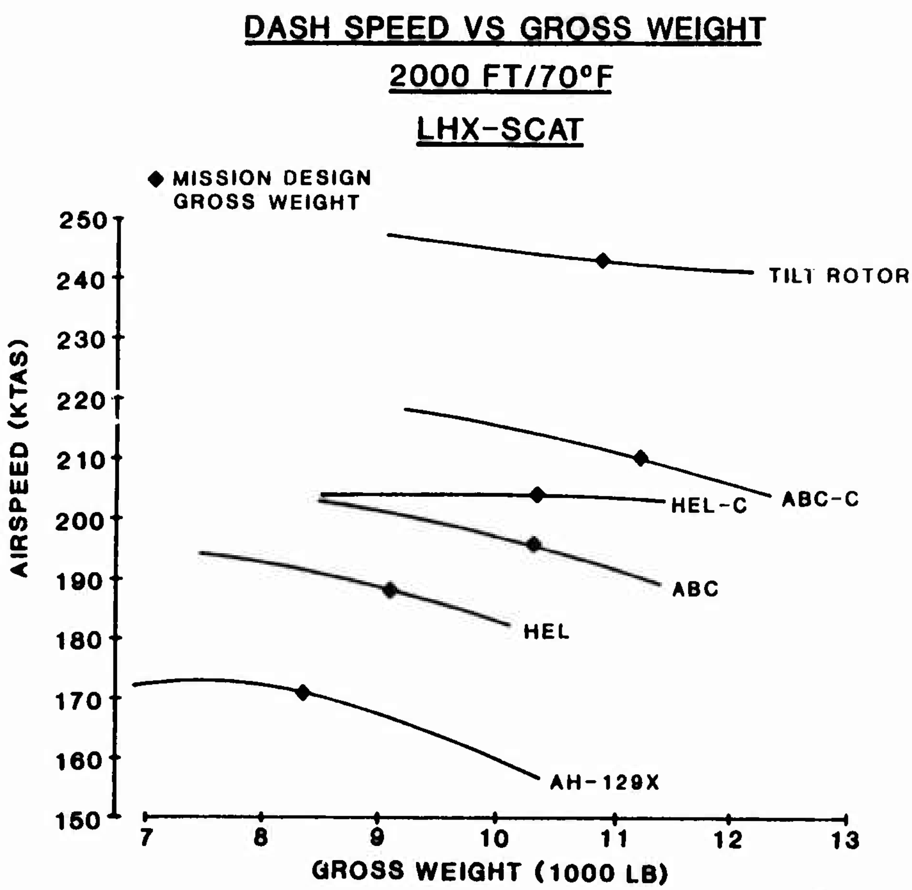

Figure N-VI-20. SCAT intermedite rated power speed, 2,000'/70°F.

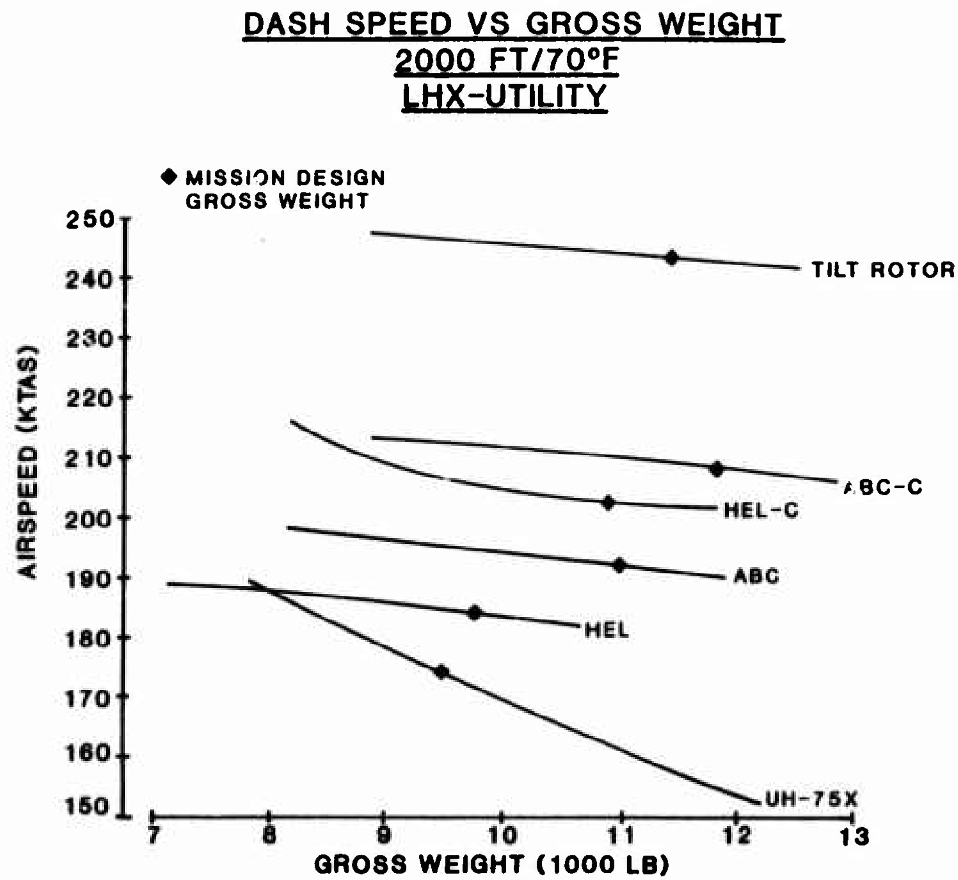

Figure N-VI-21. Utility intermediate rated power speed, 2,000'/70°F.

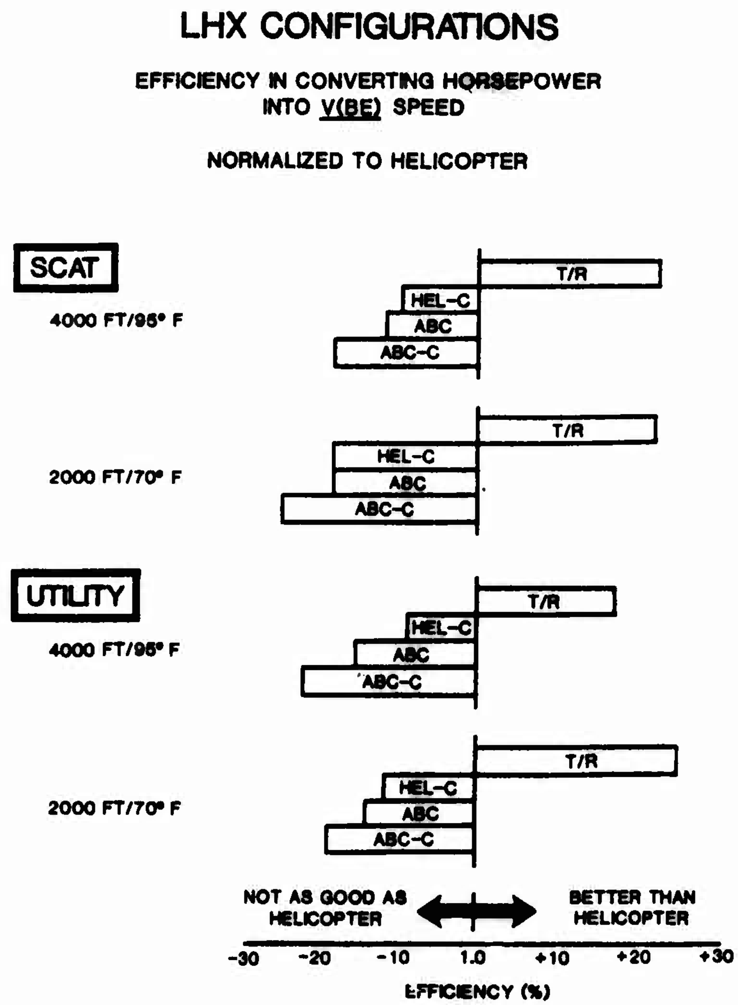

Figure N-VI-22. V(BE) speed efficiency summary.

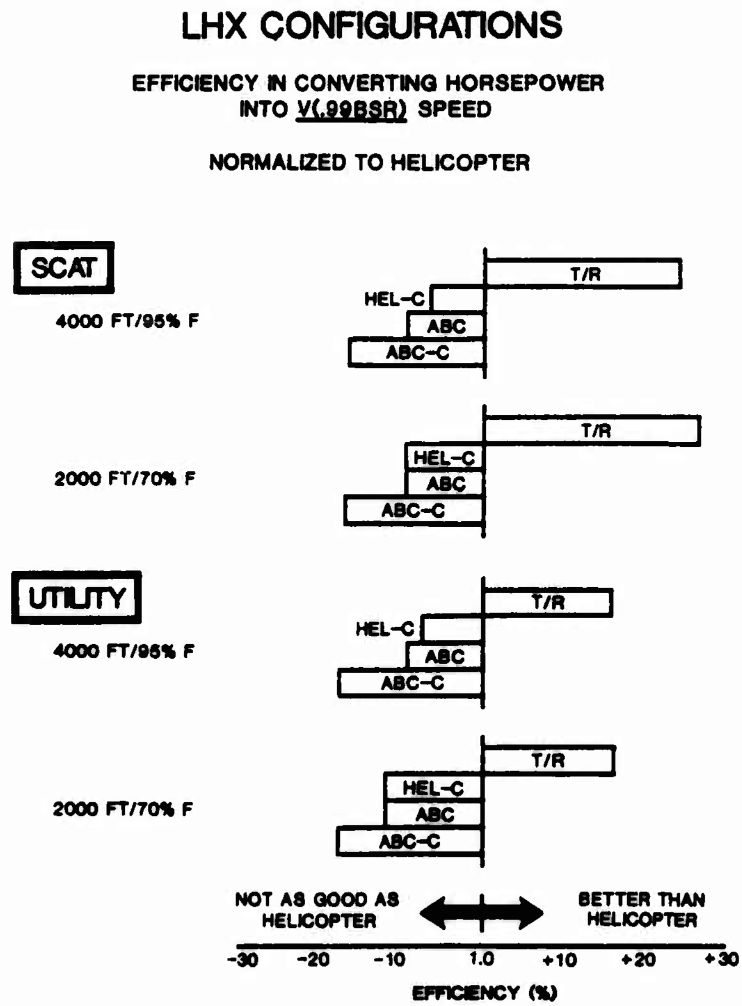

Figure N-VI-23. V(.99BSR) speed efficiency summary.

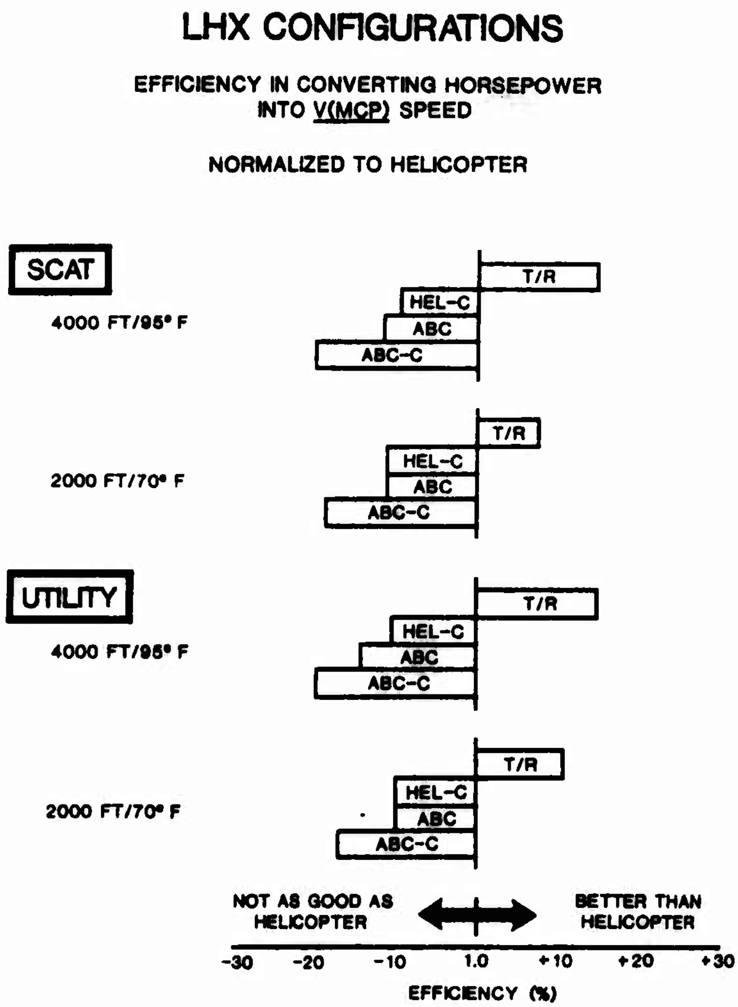

Figure N-VI-24. V(MCP) speed efficiency summary.

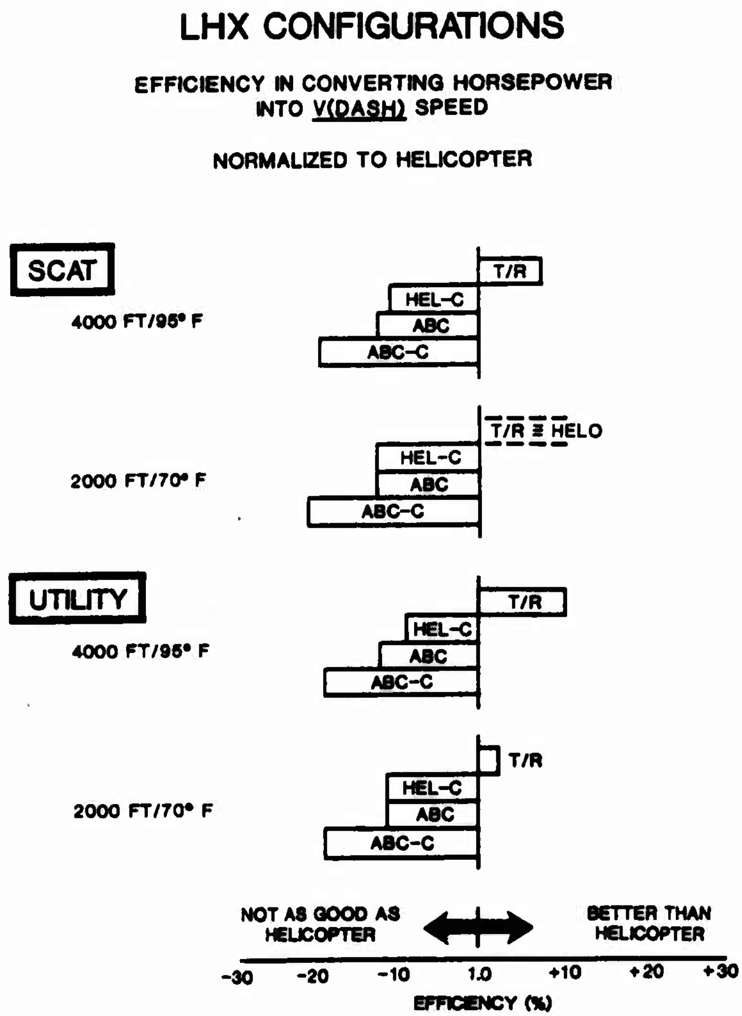

Figure N-VI-25. V(IRP) speed efficiency summary.

LHX PRODUCTIVITY

MISSION NUMBER	TITLE	FLIGHT POLICY	AIRCRAFT TYPE	MISSION TIME (HOURS)	MISSION DISTANCE (KM)	EXPOSURE TIME (HOURS)	EXPOSURE DISTANCE (KM)
03	ANTIARM	0-25 FEET	HEL/SCAT	0.674	164.200	0.039	0.414
08	DEEPSTR E	0-25 FEET	HEL/SCAT	2.590	640.000	0.175	53.080
14	SOFSTR M	0-25 FEET	HEL/SCAT	5.990	1800.000	0.213	52.240
32	SOFINS E	0-25 FEET	HEL/UTIL	7.300	1800.000	0.119	50.340
35	SOFINS M	0-25 FEET	HEL/UTIL	7.120	1800.000	0.149	41.420
03	ANTIARM	0-25 FEET	HEL COM/SCAT	0.646	164.200	0.039	0.470
08	DEEPSTR E	0-25 FEET	HEL COM/SCAT	2.360	640.000	0.167	50.690
14	SOFSTR M	0-25 FEET	HEL COM/SCAT	6.100	1800.000	0.203	54.300
32	SOFINS E	0-25 FEET	HEL COM/SCAT	6.480	1800.000	0.130	48.540
35	SOFINS M	0-25 FEET	HEL COM/SCAT	6.100	1800.000	0.131	41.840
03	ANTIARM	0-25 FEET	ABC/SCAT	0.663	163.500	0.044	1.910
08	DEEPSTR E	0-25 FEET	ABC/SCAT	2.480	640.000	0.169	58.690
14	SOFSTR M	0-25 FEET	ABC/SCAT	6.500	1800.000	0.222	55.210
32	SOFINS E	0-25 FEET	ABC/UTIL	7.030	1800.000	0.140	49.180
35	SOFINS M	0-25 FEET	ABC/UTIL	7.020	1800.000	0.160	44.440
03	ANTIARM	0-25 FEET	ABC COM/SCAT	0.630	163.000	0.040	0.840
08	DEEPSTR E	0-25 FEET	ABC COM/SCAT	2.330	640.000	0.169	53.550
14	SOFSTR M	0-25 FEET	ABC COM/SCAT	6.020	1800.000	0.200	52.840
32	SOFINS E	0-25 FEET	ABC COM/UTIL	6.360	1800.000	0.146	51.530
35	SOFINS M	0-25 FEET	ABC COM/UTIL	6.130	1800.000	0.113	38.330
03	ANTIARM	0-25 FEET	T/R SCAT	0.669	167.900	0.044	2.190
08	DEEPSTR E	0-25 FEET	T/R SCAT	1.750	640.000	0.170	67.240
14	SOFSTR M	0-25 FEET	T/R SCAT	3.120	1800.000	0.178	55.730
32	SOFINS E	0-25 FEET	T/R UTIL	4.910	1800.000	0.069	49.330
35	SOFINS M	0-25 FEET	T/R UTIL	4.750	1800.000	0.123	48.930

Figure N-VI-26. LHX mission statistics (0-25 feet).

LHX PRODUCTIVITY

MISSION NUMBER	TITLE	FLIGHT POLICY	AIRCRAFT TYPE	MISSION TIME (HOURS)	MISSION DISTANCE (KM)	EXPOSURE TIME (HOURS)	EXPOSURE DISTANCE (KM)
03	ANTIARM	0-150 FEET	HEL/SCAT	0.680	164.990	0.061	3.980
08	DEEPSTR E	0-150 FEET	HEL/SCAT	2.504	640.000	0.248	76.860
14	SOFSTR M	0-150 FEET	HEL/SCAT	6.787	1800.000	0.281	62.980
32	SOFINS E	0-150 FEET	HEL/UTIL	7.295	1800.000	0.190	56.600
36	SOFINS M	0-150 FEET	HEL/UTIL	7.105	1800.000	0.203	58.780
03	ANTIARM	0-150 FEET	HEL COM/SCAT	0.642	165.000	0.044	2.680
08	DEEPSTR E	0-150 FEET	HEL COM/SCAT	2.269	640.000	0.244	80.640
14	SOFSTR M	0-150 FEET	HEL COM/SCAT	6.094	1800.000	0.259	80.120
32	SOFINS E	0-150 FEET	HEL COM/SCAT	6.446	1800.000	0.171	45.560
36	SOFINS M	0-150 FEET	HEL COM/SCAT	6.088	1800.000	0.195	49.200
03	ANTIARM	0-150 FEET	ABC/SCAT	0.663	164.600	0.046	2.270
08	DEEPSTR E	0-150 FEET	ABC/SCAT	2.368	640.000	0.254	81.160
14	SOFSTR M	0-150 FEET	ABC/SCAT	6.497	1800.000	0.278	71.700
32	SOFINS E	0-150 FEET	ABC/UTIL	7.018	1800.000	0.193	57.340
36	SOFINS M	0-150 FEET	ABC/UTIL	7.007	1800.000	0.108	62.340
03	ANTIARM	0-150 FEET	ABC COM/SCAT	0.619	152.500	0.042	1.690
08	DEEPSTR E	0-150 FEET	ABC COM/SCAT	2.224	640.000	0.208	71.260
14	SOFSTR M	0-150 FEET	ABC COM/SCAT	6.002	1800.000	0.225	56.360
32	SOFINS E	0-150 FEET	ABC COM/UTIL	6.349	1800.000	0.193	56.870
36	SOFINS M	0-150 FEET	ABC COM/UTIL	6.122	1800.000	0.191	61.530
03	ANTIARM	0-150 FEET	T/R SCAT	0.558	156.987	0.049	5.500
08	DEEPSTR E	0-150 FEET	T/R SCAT	1.868	640.000	0.186	75.900
14	SOFSTR M	0-150 FEET	T/R SCAT	4.699	1800.000	0.220	83.400
32	SOFINS E	0-150 FEET	T/R UTIL	4.900	1800.000	0.140	34.260
36	SOFINS M	0-150 FEET	T/R UTIL	4.752	1800.000	0.186	60.650

Figure N-VI-27. LHX mission statistics (0-150 feet).

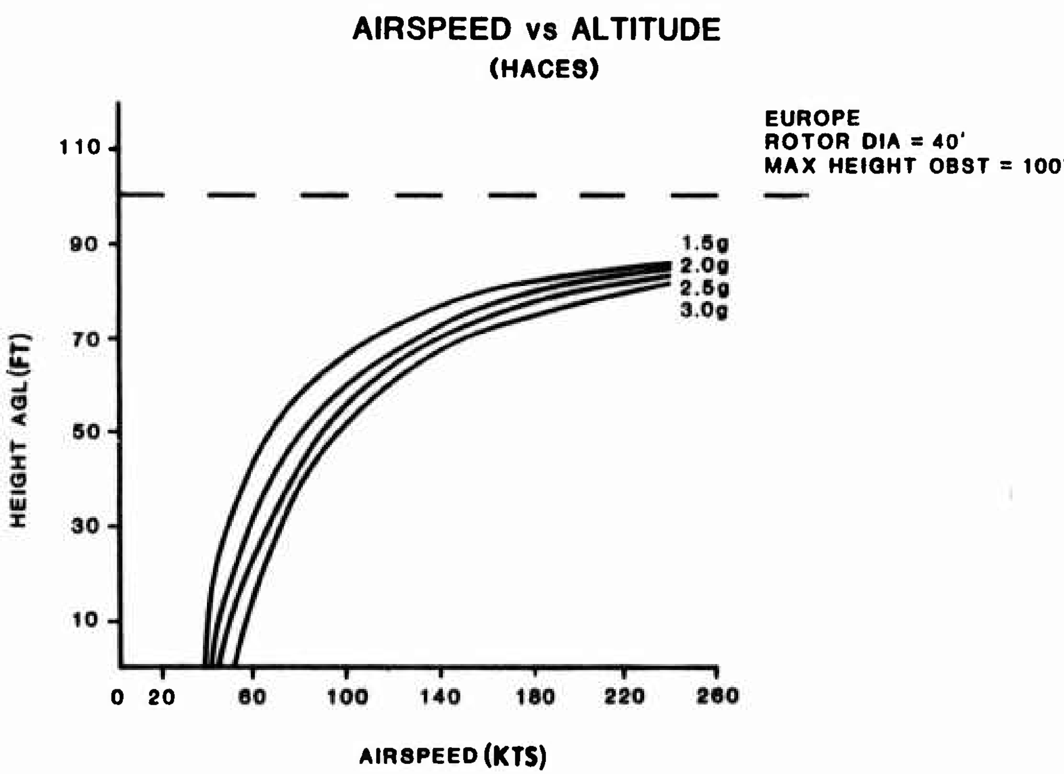

Figure N-VI-28. Altitude versus airspeed relationship (HACES).

with two altitude bands, 0-25 ft and 0-150 ft, and with six configurations: helicopter, compound helicopter, ABC, compound ABC, TR, and A129. This narrative will discuss the results of one mission analysis plus the overall results. The remaining ANOVA results are at figures N-VI-29 through N-VI-31 and displays the results for each mission.

(1) Figure N-VI-32 presents the ANOVA results for mission 3, anti-armor-Europe. The first two runs in HELMS allowed the aircraft to fly up to maximum velocity while being required to stay within the altitude bands, 0-25 ft and 0-150 ft. An examination of the raw effects shows there was no difference in mission time due to altitude; however, configuration type did cause a significant difference. When the A129 was removed from the analysis, mission time became equal indicating the variation was due to the A129 and not among the remaining five aircraft.

(2) The second set of runs increased the maneuverability/agility (M/A) parameters of the aircraft by 50 percent and exercised them over the same flight routes with the same altitude bands. An examination of this case reveals no significant differences in mission time due to either altitude or configuration type. When the A129 was removed, variation in mission time occurred as it did when both the A129 and TR were removed. This indicates the A129 and TR had a smoothing affect on mission time when considered with the other four but when removed, the remaining four configurations had a significant amount of variation among them. The third set of runs was made with a 50 percent reduction in M/A parameters and was again exercised with the same flight policies. When the M/A capabilities of the aircraft were decreased, there was no variation in mission time due to altitude; however, there was variation attributed to configuration type. The removal of the A129 eliminated the variation indicating the A129 was the source of variation and the remaining configurations were not significantly different with respect to mission time.

(3) A similar analysis was followed for total exposure time. The only significant variation occurred in the second set of runs. The variation was attributable to the TR in both the increased and decreased M/A cases.

(4) An examination of each of the remaining missions reveals similar results as above.

(a) There was little variation in mission completion time due to altitude differences. What variation did exist was generally attributed to the A129.

(b) Configuration type did cause a variation in mission completion time; however, in most cases, the variation was attributable to the A129 and/or TR.

ANOVA RESULTS

MISSION	STATS	TREATMENT	(6 A/C) R	(6 A/C) C	(6 A/C) I	(- DERIV) R	(- DERIV) C	(- DERIV) I	(-DERIV&T/R) R	(-DERIV&T/R) C	(-DERIV&T/R) I
		R C									
3 MSV	MSN TIME	ALTITUDE A/C TYPE	NE	NE	NE	NE	NE	E	NE	E	E
	MSN DIST	ALTITUDE A/C TYPE	E	E	-	E	E	-	E	E	-
	EXP TIME	ALTITUDE A/C TYPE	NE	NE	E	NE	E	E	NE	E	E
	EXP DIST	ALTITUDE A/C TYPE	NE	NE	E	NE	E	E	NE	E	E
		R C									
3 160% H/A	MSN TIME	ALTITUDE A/C TYPE	E	NE	-	E	NE	E	E	E	E
	MSN DIST	ALTITUDE A/C TYPE	E	E	-	E	E	-	E	E	-
	EXP TIME	ALTITUDE A/C TYPE	NE	NE	E	NE	NE	E	NE	E	E
	EXP DIST	ALTITUDE A/C TYPE									
		R C									
3 50% H/A	MSN TIME	ALTITUDE A/C TYPE	NE	NE	NE	NE	NE	NE	NE	E	E
	MSN DIST	ALTITUDE A/C TYPE	NE	NE	-	E	E	-	NE	NE	-
	EXP TIME	ALTITUDE A/C TYPE	NE	E	E	NE	NE	NE	NE	NE	E
	EXP DIST	ALTITUDE A/C TYPE	NE	E	E	NE	E	E	NE	E	E

Figure N-VI-29. Mission 3 ANOVA results.

ANOVA RESULTS

MISSION	STATS	TREATMENT	(6 A/C) R	(6 A/C) C	(6 A/C) I	(- DERIV) R	(- DERIV) C	(- DERIV) I	(-DERIV&T/R) R	(-DERIV&T/R) C	(-DERIV&T/R) I
		R C									
14 MSV(1)	MSN TIME	ALTITUDE A/C TYPE	E	NE	E	E	NE	E	E	E	E
	MSN DIST	ALTITUDE A/C TYPE	E	E	-	E	E	-	E	E	-
	EXP TIME	ALTITUDE A/C TYPE	E	E	E	E	E	E	E	E	E
	EXP DIST	ALTITUDE A/C TYPE	NE	E	E	E	E	E	E	E	E
		R C									
14 MSV(2)	MSN TIME	ALTITUDE A/C TYPE	NE	NE	E	E	NE	E	E	NE	E
	MSN DIST	ALTITUDE A/C TYPE	E	E	-	E	E	-	E	E	-
	EXP TIME	ALTITUDE A/C TYPE	NE	NE	NE	NE	NE	E	NE	NE	N
	EXP DIST	ALTITUDE A/C TYPE	NE	E	E	NE	NE	NE	NE	NE	N
		R C									
14 MSV(3)	MSN TIME	ALTITUDE A/C TYPE	NE	NE	E	NE	NE	E	NE	E	-
	MSN DIST	ALTITUDE A/C TYPE	NE	E	-	NE	E	-	NE	E	E
	EXP TIME	ALTITUDE A/C TYPE	E	E	E	E	E	E	E	E	E
	EXP DIST	ALTITUDE A/C TYPE	E	E	E	E	E	E	E	E	E
		R C									
14 150%M/A(1)	MSN TIME	ALTITUDE A/C TYPE	E	NE	E	E	NE	E	E	E	E
	MSN DIST	ALTITUDE A/C TYPE	E	E	-	E	E	-	E	E	-
	EXP TIME	ALTITUDE A/C TYPE	E	E	E	E	E	E	E	E	E
	EXP DIST	ALTITUDE A/C TYPE	E	E	E	E	E	E	E	E	E
		R C									
14 150%M/A(2)	MSN TIME	ALTITUDE A/C TYPE	E	NE	E	E	NE	E	E	NE	E
	MSN DIST	ALTITUDE A/C TYPE	E	E	-	E	E	-	E	E	-
	EXP TIME	ALTITUDE A/C TYPE	NE	E	E	E	E	E	E	E	E
	EXP DIST	ALTITUDE A/C TYPE	NE	E	E	E	E	E	E	E	E
		R C									
14 150%M/A(3)	MSN TIME	ALTITUDE A/C TYPE	NE	NE	NE	NE	E	E	E	E	E
	MSN DIST	ALTITUDE A/C TYPE	E	E	-	E	E	E	E	E	E
	EXP TIME	ALTITUDE A/C TYPE	NE	E	NE	NE	E	-	E	E	E
	EXP DIST	ALTITUDE A/C TYPE	E	E	E	E	E	E	E	E	E
		R C									
14 50%M/A(1)	MSN TIME	ALTITUDE A/C TYPE	NE	NE	E	NE	NE	E	NE	NE	E
	MSN DIST	ALTITUDE A/C TYPE	E	NE	E	E	E	E	E	E	-
	EXP TIME	ALTITUDE A/C TYPE	NE	E	E	E	E	E	E	E	E
	EXP DIST	ALTITUDE A/C TYPE	NE	E	E	E	E	E	E	E	E
		R C									
14 50%M/A(2)	MSN TIME	ALTITUDE A/C TYPE	E	NE	E	NE	NE	NE	E	E	E
	MSN DIST	ALTITUDE A/C TYPE	NE	NE	NE	E	NE	NE	E	E	-
	EXP TIME	ALTITUDE A/C TYPE	NE	E	E	NE	E	E	E	E	E
	EXP DIST	ALTITUDE A/C TYPE	NE	E	E	NE	E	E	NE	E	E
		R C									
14 50%M/A(3)	MSN TIME	ALTITUDE A/C TYPE	NE	NE	E	E	NE	E	E	E	-
	MSN DIST	ALTITUDE A/C TYPE	NE	NE	-	NE	NE	-	NE	E	-
	EXP TIME	ALTITUDE A/C TYPE	NE	NE	E	NE	NE	NE	NE	E	E
	EXP DIST	ALTITUDE A/C TYPE	NE	E	E	NE	E	E	NE	E	E

Figure N-VI-30. Mission 14 ANOVA results.

ANOVA RESULTS

MISSION	STATS	TREATMENT	(6 A/C) R	(6 A/C) C	(6 A/C) I	(- DERIV) R	(- DERIV) C	(- DERIV) I	(-DERIV&T/R) R	(-DERIV&T/R) C	(-DERIV&T/R) I
		R C									
32 MSV	MSN TIME	ALTITUDE A/C TYPE	E	NE	-	E	NE	E	E	NE	E
	MSN DIST	ALTITUDE A/C TYPE	E	E	-	E	E	-	E	E	-
	EXP TIME	ALTITUDE A/C TYPE	NE	NE	NE	NE	NE	E	NE	E	E
	EXP DIST	ALTITUDE A/C TYPE	NE	NE	E	NE	E	E	NE	E	E
		R C									
32 100% H/A	MSN TIME	ALTITUDE A/C TYPE	E	NE	-	E	NE	E	E	NE	E
	MSN DIST	ALTITUDE A/C TYPE	E	E	-	E	E	-	E	E	-
	EXP TIME	ALTITUDE A/C TYPE	NE	NE	NE	NE	NE	E	NE	E	-
	EXP DIST	ALTITUDE A/C TYPE	NE	E	E	NE	E	E	NE	E	-
		R C									
32 50% H/A	MSN TIME	ALTITUDE A/C TYPE	E	NE	E	NE	NE	E	NE	NE	-
	MSN DIST	ALTITUDE A/C TYPE	NE	E	-	NE	E	-	E	E	-
	EXP TIME	ALTITUDE A/C TYPE	NE	NE	NE	NE	NE	E	NE	NE	N
	EXP DIST	ALTITUDE A/C TYPE	NE	E	NE	NE	E	NE	NE	E	NE

Figure N-VI-31. Mission 32 ANOVA results.

ANOVA RESULTS

MISSION	STATS	TREATMENT	(6 A/C) R	(6 A/C) C	(6 A/C) I	(- DERIV) R	(- DERIV) C	(- DERIV) I	(-DERIV&T/R) R	(-DERIV&T/R) C	(-DERIV&T/R) I
		R C									
3 MSV	MSN TIME	ALTITUDE A/C TYPE	E	NE	E	E	E	E	E	E	-
	MSN DIST	ALTITUDE A/C TYPE	NE	E	-	NE	E	-	E	E	-
	EXP TIME	ALTITUDE A/C TYPE	E	E	E	E	E	E	E	E	E
	EXP DIST	ALTITUDE A/C TYPE	NE	E	E	E	E	E	E	E	E
		R C									
3 150% H/A	MSN TIME	ALTITUDE A/C TYPE	E	E	-	NE	E	NE	NE	NE	NE
	MSN DIST	ALTITUDE A/C TYPE	E	E	E	NE	NE	NE	E	E	E
	EXP TIME	ALTITUDE A/C TYPE	E	NE	NE	NE	NE	NE	E	E	E
	EXP DIST	ALTITUDE A/C TYPE	E	E	E	NE	NE	NE	E	E	E
		R C									
3 50% H/A	MSN TIME	ALTITUDE A/C TYPE	E	NE	E	E	E	E	E	E	-
	MSN DIST	ALTITUDE A/C TYPE	NE	E	-	NE	E	-	NE	E	-
	EXP TIME	ALTITUDE A/C TYPE	NE	E	E	NE	E	E	E	E	E
	EXP DIST	ALTITUDE A/C TYPE	NE	E	NE	NE	E	E	E	E	E

Figure N-VI-32. Mission 3 ANOVA results.

(c) Exposure time was generally affected by altitude on those missions or mission segments where a significant threat existed. This result is logical due to the increased probability of clear line of sight that exists at higher flight altitudes.

(d) The variation in exposure time due to configuration type followed a similar pattern as did the altitude bands. On those mission segments where the threat existed, variations occurred. A further examination reveals that generally the variation was attributable to the A129 and TR. With these two removed from the ANOVA, there were not significant differences among the remaining four configurations.

h. Further Statistical Analysis. The next phase of the analysis looked at differences in the relevant statistics inherent with each of the configurations. Figures N-VI-33 and N-VI-34 present the results for the productivity comparisons. The mission frequencies are from the LHX mission profile prioritization Delphi process and represent the frequency each mission would be performed over a 15-day period. The weighted average mission time was calculated by multiplying the mission time by the mission frequency. The weighted averages were then normalized to the helicopter values. As can be seen in figure N-VI-33, the TR has an advantage over the helicopter ranging from 16-56 percent. As the mission distance increases, the faster aircraft's advantage is increased. The shortest mission was antiarmor-Europe (3) with the TR having a 15.6-percent advantage over the helicopter. The remaining configurations' advantages ranged from 3 to 6.5 percent. The ANOVA results showed that this was not a statistically significant difference. On mission 14, which had a mission distance of 1,800 kilometers, the two compounds showed approximately a 12 percent advantage over the helicopter while the TR had a 43 percent advantage over the compounds and a 55 percent advantage over the helicopter. It can be seen then that the TR holds a significant advantage over the other configurations with the two compounds holding only a slight advantage over the helicopter. The ABC had no significant difference in mission times. The same type of results hold for both the 0-25 ft and 0-150 ft cases. The normalized mission time results for each mission are summarized in figures N-VI-35 and N-VI-36.

LHX PRODUCTIVITY

MISSION NUMBER	TITLE	FLIGHT POLICY	AIRCRAFT TYPE	MISSION TIME (HOURS)	MISSION FREQUENCY	WEIGHTED AVERAGE MISSION TIME	NORMALIZED TO HELO	COMPOSITE NORMALIZATION	
03	ANTIARM	0-25 FEET	HEL/SCAT	0.674	0.039	0.026	1.000		
08	DEEPSTR E	0-25 FEET	HEL/SCAT	2.590	0.017	0.044	1.000		
14	SOFSTR N	0-25 FEET	HEL/SCAT	6.990	0.016	0.112	1.000		
32	SOFINS E	0-25 FEET	HEL/UTIL	7.300	0.018	0.131	1.000		
36	SOFINS N	0-25 FEET	HEL/UTIL	7.120	0.019	0.136	1.000	0.449	HEL
03	ANTIARM	0-25 FEET	HEL COM/SCAT	0.646	0.039	0.025	0.957		
08	DEEPSTR E	0-25 FEET	HEL COM/SCAT	2.360	0.017	0.040	0.911		
14	SOFSTR N	0-25 FEET	HEL COM/SCAT	6.100	0.016	0.098	0.873		
32	SOFINS E	0-25 FEET	HEL COM/SCAT	6.480	0.018	0.117	0.888		
36	SOFINS N	0-25 FEET	HEL COM/SCAT	6.100	0.019	0.116	0.857	0.395	HELCOMP
03	ANTIARM	0-25 FEET	ABC/SCAT	0.663	0.039	0.026	0.984		
08	DEEPSTR E	0-25 FEET	ABC/SCAT	2.460	0.017	0.042	0.950		
14	SOFSTR N	0-25 FEET	ABC/SCAT	6.500	0.016	0.104	0.930		
32	SOFINS E	0-25 FEET	ABC/UTIL	7.030	0.018	0.127	0.963		
36	SOFINS N	0-25 FEET	ABC/UTIL	7.020	0.019	0.133	0.986	0.432	ABC
03	ANTIARM	0-25 FEET	ABC COM/SCAT	0.630	0.039	0.025	0.935		
08	DEEPSTR E	0-25 FEET	ABC COM/SCAT	2.330	0.017	0.040	0.900		
14	SOFSTR N	0-25 FEET	ABC COM/SCAT	6.020	0.016	0.096	0.861		
32	SOFINS E	0-25 FEET	ABC COM/UTIL	6.360	0.018	0.114	0.871		
36	SOFINS N	0-25 FEET	ABC COM/UTIL	6.130	0.019	0.116	0.861	0.391	ABCCOM
03	ANTIARM	0-25 FEET	T/R SCAT	0.569	0.039	0.022	0.844		
08	DEEPSTR E	0-25 FEET	T/R SCAT	1.750	0.017	0.030	0.676		
14	SOFSTR N	0-25 FEET	T/R SCAT	3.120	0.016	0.050	0.446		
32	SOFINS E	0-25 FEET	T/R UTIL	4.910	0.018	0.088	0.673		
36	SOFINS N	0-25 FEET	T/R UTIL	4.750	0.019	0.090	0.667	0.280	T/R

Figure N-VI-33. LHX productivity (0-25 feet).

LHX PRODUCTIVITY

MISSION NUMBER	TITLE	FLIGHT POLICY	AIRCRAFT TYPE	MISSION TIME (HOURS)	MISSION FREQUENCY	WEIGHTED AVERAGE MISSION TIME	NORMALIZED TO HELO	COMPOSITE NORMALIZATION	
03	ANTIARM	0-150 FEET	HEL/SCAT	0.880	0.039	0.027	1.000		
08	DEEPSTR E	0-150 FEET	HEL/SCAT	2.504	0.017	0.043	1.000		
14	SOFSTR M	0-150 FEET	HEL/SCAT	6.787	0.016	0.109	1.000		
32	SOFINS E	0-150 FEET	HEL/UTIL	7.295	0.018	0.131	1.000		
35	SOFINS M	0-150 FEET	HEL/UTIL	7.105	0.019	0.135	1.000	0.444	HEL
03	ANTIARM	0-150 FEET	HEL COM/SCAT	0.842	0.039	0.025	0.944		
08	DEEPSTR E	0-150 FEET	HEL COM/SCAT	2.289	0.017	0.039	0.908		
14	SOFSTR M	0-150 FEET	HEL COM/SCAT	6.094	0.016	0.098	0.899		
32	SOFINS E	0-150 FEET	HEL COM/SCAT	6.446	0.018	0.116	0.884		
35	SOFINS M	0-150 FEET	HEL COM/SCAT	6.088	0.019	0.115	0.854	0.392	HELCOMP
03	ANTIARM	0-150 FEET	ABC/SCAT	0.883	0.039	0.027	1.004		
08	DEEPSTR E	0-150 FEET	ABC/SCAT	2.380	0.017	0.040	0.946		
14	SOFSTR M	0-150 FEET	ABC/SCAT	6.497	0.016	0.104	0.957		
32	SOFINS E	0-150 FEET	ABC/UTIL	7.018	0.018	0.126	0.962		
35	SOFINS M	0-150 FEET	ABC/UTIL	7.007	0.019	0.133	0.986	0.430	ABC
03	ANTIARM	0-150 FEET	ABC COM/SCAT	0.819	0.039	0.024	0.910		
08	DEEPSTR E	0-150 FEET	ABC COM/SCAT	2.224	0.017	0.038	0.888		
14	SOFSTR M	0-150 FEET	ABC COM/SCAT	6.002	0.016	0.096	0.884		
32	SOFINS E	0-150 FEET	ABC COM/UTIL	6.349	0.018	0.114	0.870		
35	SOFINS M	0-150 FEET	ABC COM/UTIL	6.122	0.019	0.116	0.862	0.388	ABCCOM
03	ANTIARM	0-150 FEET	T/R SCAT	0.558	0.039	0.022	0.821		
08	DEEPSTR E	0-150 FEET	T/R SCAT	1.688	0.017	0.029	0.666		
14	SOFSTR M	0-150 FEET	T/R SCAT	4.899	0.016	0.075	0.692		
32	SOFINS E	0-150 FEET	T/R UTIL	4.900	0.018	0.088	0.672		
35	SOFINS M	0-150 FEET	T/R UTIL	4.752	0.019	0.090	0.669	0.304	T/R

Figure N-VI-34. LHX productivity (0-150 feet).

MISSION NUMBER	TITLE	FLIGHT POLICY	AIRCRAFT TYPE	NORMALIZED TO HELO
03	ANTIARM	0-25 FEET	HEL/SCAT	1.000
08	DEEPSTR E	0-25 FEET	HEL/SCAT	1.000
14	SOFSTR M	0-25 FEET	HEL/SCAT	1.000
32	SOFINS E	0-25 FEET	HEL/UTIL	1.000
35	SOFINS M	0-25 FEET	HEL/UTIL	1.000
03	ANTIARM	0-25 FEET	HEL COM/SCAT	0.957
08	DEEPSTR E	0-25 FEET	HEL COM/SCAT	0.911
14	SOFSTR M	0-25 FEET	HEL COM/SCAT	0.873
32	SOFINS E	0-25 FEET	HEL COM/SCAT	0.898
35	SOFINS M	0-25 FEET	HEL COM/SCAT	0.957
03	ANTIARM	0-25 FEET	ABC/SCAT	0.994
08	DEEPSTR E	0-25 FEET	ABC/SCAT	0.950
14	SOFSTR M	0-25 FEET	ABC/SCAT	0.930
32	SOFINS E	0-25 FEET	ABC/UTIL	0.983
35	SOFINS M	0-25 FEET	ABC/UTIL	0.998
03	ANTIARM	0-25 FEET	ABC COM/SCAT	0.935
08	DEEPSTR E	0-25 FEET	ABC COM/SCAT	0.900
14	SOFSTR M	0-25 FEET	ABC COM/SCAT	0.881
32	SOFINS E	0-25 FEET	ABC COM/UTIL	0.871
35	SOFINS M	0-25 FEET	ABC COM/UTIL	0.881
03	ANTIARM	0-25 FEET	T/R SCAT	0.944
08	DEEPSTR E	0-25 FEET	T/R SCAT	0.678
14	SOFSTR M	0-25 FEET	T/R SCAT	0.448
32	SOFINS E	0-25 FEET	T/R UTIL	0.673
35	SOFINS M	0-25 FEET	T/R UTIL	0.867

Figure N-VI-35. Summary normalized weighted mission times (0-25 feet).

MISSION NUMBER	TITLE	FLIGHT POLICY	AIRCRAFT TYPE	NORMALIZED TO HELO
03	ANTIARM	0-150 FEET	HEL/SCAT	1.000
08	DEEPSTR E	0-150 FEET	HEL/SCAT	1.000
14	SOFSTR H	0-150 FEET	HEL/SCAT	1.000
32	SOFINS E	0-150 FEET	HEL/UTIL	1.000
35	SOFINS H	0-150 FEET	HEL/UTIL	1.000
03	ANTIARM	0-150 FEET	HEL COM/SCAT	0.944
08	DEEPSTR E	0-150 FEET	HEL COM/SCAT	0.906
14	SOFSTR H	0-150 FEET	HEL COM/SCAT	0.898
32	SOFINS E	0-150 FEET	HEL COM/SCAT	0.884
35	SOFINS H	0-150 FEET	HEL COM/SCAT	0.854
03	ANTIARM	0-150 FEET	ABC/SCAT	1.004
08	DEEPSTR E	0-150 FEET	ABC/SCAT	0.946
14	SOFSTR H	0-150 FEET	ABC/SCAT	0.957
32	SOFINS E	0-150 FEET	ABC/UTIL	0.982
35	SOFINS H	0-150 FEET	ABC/UTIL	0.986
03	ANTIARM	0-150 FEET	ABC COM/SCAT	0.910
08	DEEPSTR E	0-150 FEET	ABC COM/SCAT	0.888
14	SOFSTR H	0-150 FEET	ABC COM/SCAT	0.884
32	SOFINS E	0-150 FEET	ABC COM/UTIL	0.870
35	SOFINS H	0-150 FEET	ABC COM/UTIL	0.882
03	ANTIARM	0-150 FEET	T/R SCAT	0.821
08	DEEPSTR E	0-150 FEET	T/R SCAT	0.866
14	SOFSTR H	0-150 FEET	T/R SCAT	0.892
32	SOFINS E	0-150 FEET	T/R UTIL	0.872
35	SOFINS H	0-150 FEET	T/R UTIL	0.869

Figure N-VI-36. Summary normalized weighted mission times (0-150 feet).

i. <u>Productivity Measure</u>. To obtain a productivity measure across all missions, the weighted average mission times were summed over all missions for each aircraft configuration. These results can be seen in figures N-VI-37 through N-VI-40. The SCAT results for the 0-25 ft cases, when normalized to the helicopter, reveal a 44 percent advantage for the TR, a 12 percent advantage for the ABC compound, a 5 percent advantage for the ABC, and a 10 percent advantage for the compound helicopter. The Utility statistics follow the same trend as the SCAT.

j. <u>Excursion Analysis</u>. An excursion was made to examine the effects of exposure time on productivity. Missions 14 and 35 were modified by stripping the total exposure time from the mission time, then adding back a factor derived by multiplying the exposure distance by 40 knots. The assumption was made when an exposure occurred the aircraft would break line of sight and fly the distance nap of the earth (NOE) (40 knots). The resultant modified mission times were then compared. The results in figure N-VI-41 show that even when all configurations react exactly the same to the threat by flying NOE, the TR still maintains a 12-15 percent advantage over the helicopter.

SCAT PRODUCTIVITY

MISSION NUMBER	TITLE	FLIGHT POLICY	AIRCRAFT TYPE	MISSION TIME (HOURS)	MISSION FREQUENCY	WEIGHTED AVERAGE MISSION TIME	NORMALIZED TO HELO	COMPOSITE NORMALIZATION	
03	ANTIARM	0-25 FEET	HEL/SCAT	0.674	0.039	0.026	1.000		
08	DEEPSTR E	0-25 FEET	HEL/SCAT	2.590	0.017	0.044	1.000		
14	SOFSTR M	0-25 FEET	HEL/SCAT	6.990	0.016	0.112	1.000	0.182	HELO
03	ANTIARM	0-25 FEET	HEL COM/SCAT	0.646	0.039	0.025	0.957		
08	DEEPSTR E	0-25 FEET	HEL COM/SCAT	2.360	0.017	0.040	0.911		
14	SOFSTR M	0-25 FEET	HEL COM/SCAT	6.100	0.016	0.098	0.873	0.163	HELO COMP
03	ANTIARM	0-25 FEET	ABC/SCAT	0.663	0.039	0.026	0.984		
08	DEEPSTR E	0-25 FEET	ABC/SCAT	2.460	0.017	0.042	0.950		
14	SOFSTR M	0-25 FEET	ABC/SCAT	6.500	0.016	0.104	0.930	0.172	ABC
03	ANTIARM	0-25 FEET	ABC COM/SCAT	0.630	0.039	0.025	0.936		
08	DEEPSTR E	0-25 FEET	ABC COM/SCAT	2.330	0.017	0.040	0.900		
14	SOFSTR M	0-25 FEET	ABC COM/SCAT	6.020	0.016	0.096	0.861	0.161	ABC COMP
03	ANTIARM	0-25 FEET	T/R SCAT	0.569	0.039	0.022	0.844		
08	DEEPSTR E	0-25 FEET	T/R SCAT	1.750	0.017	0.030	0.676		
14	SOFSTR M	0-25 FEET	T/R SCAT	3.120	0.016	0.050	0.446	0.102	T/R

Figure N-VI-37. SCAT productivity (0-25 feet).

UTILITY PRODUCTIVITY

MISSION NUMBER	TITLE	FLIGHT POLICY	AIRCRAFT TYPE	MISSION TIME (HOURS)	MISSION FREQUENCY	WEIGHTED AVERAGE MISSION TIME	NORMALIZED TO HELO	COMPOSITE NORMALIZATION	
32	SOFINS E	0-25 FEET	HEL/UTIL	7.300	0.018	0.131	1.000		
35	SOFINS M	0-25 FEET	HEL/UTIL	7.120	0.019	0.135	1.000	0.267	HEL
32	SOFINS E	0-25 FEET	HEL COM/SCAT	6.480	0.018	0.117	0.888		
35	SOFINS M	0-25 FEET	HEL COM/SCAT	6.100	0.019	0.116	0.857	0.233	HELCOMP
32	SOFINS E	0-25 FEET	ABC/UTIL	7.030	0.018	0.127	0.963		
35	SOFINS M	0-25 FEET	ABC/UTIL	7.020	0.019	0.133	0.986	0.260	ABC
32	SOFINS E	0-25 FEET	ABC COM/UTIL	6.360	0.018	0.114	0.871		
35	SOFINS M	0-25 FEET	ABC COM/UTIL	6.130	0.019	0.116	0.861	0.231	ABCCOM
32	SOFINS E	0-25 FEET	T/R UTIL	4.910	0.018	0.088	0.673		
35	SOFINS M	0-25 FEET	T/R UTIL	4.760	0.019	0.090	0.667	0.179	T/R

Figure N-VI-38. Utility productivity (0-25 feet).

SCAT PRODUCTIVITY

MISSION NUMBER	TITLE	FLIGHT POLICY	AIRCRAFT TYPE	MISSION TIME (HOURS)	MISSION FREQUENCY	WEIGHTED AVERAGE MISSION TIME	NORMALIZED TO HELO	COMPOSITE NORMALIZATION	
03	ANTIARM	0-150 FEET	HEL/SCAT	0.680	0.039	0.027	1.000		
08	DEEPSTR E	0-150 FEET	HEL/SCAT	2.504	0.017	0.043	1.000		
14	SOFSTR M	0-150 FEET	HEL/SCAT	6.787	0.016	0.109	1.000	0.178	HELO
03	ANTIARM	0-150 FEET	HEL COM/SCAT	0.642	0.039	0.025	0.944		
08	DEEPSTR E	0-150 FEET	HEL COM/SCAT	2.289	0.017	0.039	0.906		
14	SOFSTR M	0-150 FEET	HEL COM/SCAT	6.094	0.016	0.098	0.898	0.161	HELO COMP
03	ANTIARM	0-150 FEET	ABC/SCAT	0.683	0.039	0.027	1.004		
08	DEEPSTR E	0-150 FEET	ABC/SCAT	2.368	0.017	0.040	0.946		
14	SOFSTR M	0-150 FEET	ABC/SCAT	6.497	0.016	0.104	0.957	0.171	ABC
03	ANTIARM	0-150 FEET	ABC COM/SCAT	0.619	0.039	0.024	0.910		
08	DEEPSTR E	0-150 FEET	ABC COM/SCAT	2.224	0.017	0.038	0.888		
14	SOFSTR M	0-150 FEET	ABC COM/SCAT	6.002	0.016	0.096	0.884	0.150	ABC COMP
03	ANTIARM	0-150 FEET	T/R SCAT	0.558	0.039	0.022	0.821		
08	DEEPSTR E	0-150 FEET	T/R SCAT	1.668	0.017	0.028	0.666		
14	SOFSTR M	0-150 FEET	T/R SCAT	4.699	0.016	0.075	0.692	0.125	T/R

Figure N-VI-39. SCAT productivity (0-150 feet).

UTILITY PRODUCTIVITY

MISSION NUMBER	TITLE	FLIGHT POLICY	AIRCRAFT TYPE	MISSION TIME (HOURS)	MISSION FREQUENCY	WEIGHTED AVERAGE MISSION TIME	NORMALIZED TO HELO	COMPOSITE NORMALIZATION	
32	SOFINS E	0-150 FEET	HEL/UTIL	7.295	0.018	0.131	1.000		
36	SOFINS M	0-150 FEET	HEL/UTIL	7.105	0.019	0.135	1.000	0.266	HEL
32	SOFINS E	0-150 FEET	HEL COM/SCAT	6.446	0.018	0.116	0.884		
36	SOFINS M	0-150 FEET	HEL COM/SCAT	6.089	0.019	0.116	0.854	0.237	HELCOMP
32	SOFINS E	0-150 FEET	ABC/UTIL	7.018	0.018	0.126	0.962		
36	SOFINS M	0-150 FEET	ABC/UTIL	7.007	0.019	0.133	0.985	0.259	ABC
32	SOFINS E	0-150 FEET	ABC COM/UTIL	6.349	0.018	0.114	0.870		
36	SOFINS M	0-150 FEET	ABC COM/UTIL	6.122	0.019	0.116	0.862	0.231	ABCCOM
32	SOFINS E	0-150 FEET	T/R UTIL	4.900	0.018	0.088	0.672		
36	SOFINS M	0-150 FEET	T/R UTIL	4.752	0.019	0.090	0.669	0.179	T/R

Figure N-VI-40. Utility productivity (0-150 feet).

Mission Number	Aircraft Type	Mission Time (minutes)		Exposure Time (minutes)		Factor (minutes)		Modified Mission Time (minutes)
14	HEL	54.7	-	9.1	+	27.2	=	72.8
	ABC-C	49.2	-	8.4	+	27.2	=	68.0
	TR	42.2	-	7.6	+	27.0	=	61.6
35	HEL	51.4	-	4.8	+	17.4	=	64.0
	ABC-C	46.1	-	3.3	+	14.3	=	57.1
	TR	39.5	-	4.4	+	21.5	=	56.6

Figure N-VI-41. Modified mission times.

N-VI-7. FINDINGS/CONCLUSIONS.

a. Findings.

(1) The TR speeds are significantly higher than the other LHX configurations.

(2) The TR has a large V(BE) interval because of its ability to alter/modify the configuration shape through nacelle/rotor incidence management.

(3) For the intervals analyzed, the TR transforms horsepower into speed more efficiently than the other configurations.

(4) The results of the HELMS analysis show that the various aircraft configurations possess sufficient performance capabilities to negotiate the flight routes while utilizing approximately 70 percent of their maximum speed capability. The mission completion times only increase 1 to 3 percent for the lower altitude band, indicating the configurations are capable of high speed flight at altitudes of lower than 25 ft while suffering only very minor degradations in mission time and distance with only slight decreases in exposure time.

(5) The TR experiences significant advantages in mission time over the remaining configurations. By combining all missions for both SCAT and Utility, the TR has a 38 percent advantage over the helicopter, a 35 percent advantage over the ABC, a 29 percent advantage over the helicopter-compound, and a 28 percent advantage over the ABC-compound. Other than the TR, only the ABC-compound has a greater than 10 percent advantage over the helicopter (13 percent).

(6) The mission profile prioritization Delphi process provided the mission frequencies for each mission. When these statistics were combined with the mission times and summed over all missions, similar results were obtained. This statistic weights the mission times to provide a more realistic view of the advantage of speed and results in a significant advantage for the TR with the other configurations close to the helicopter.

(7) The ANOVA results show that the only statistically significant difference in mission completion time was between the TR and helicopter; the remaining configurations had times which were very close and thus were not significant. While there was a significant difference in mission time for the TR, there was no significant difference among configurations for exposure times. The exposure times were virtually equal except for the derivative A129 SCAT and SI75 Utility. This is significant in that the TR increases productivity approximately 35-40 percent while suffering no increase in exposure time. The ANOVA also provided data that showed there was no appreciable difference in mission statistics between the two altitude bands, 0-25 ft and 0-150 ft. This is evidence that contradicts the addage "the faster you go, the higher you fly." The HELMS results show that as airspeed increases, flight altitude also increases but levels off around 20-30 ft above ground level. It is important to note that the HELMS results do not consider the human capability but only represent the aircraft's capability. It is presumed the altitudes would increase slightly if a human's tolerances were considered.

b. Conclusions.

(1) The only significant productivity gains occur with the TR configuration. These gains are based on the trade-off determination (TOD) designs with the mission equipment package (MEP) performance outlined in appendix O.

(2) Based on performance characteristics, the TOD designs are capable of high speed flight at altitudes at or below 25 ft.

(3) The combination of improved MEP and TR performance provide a substantial productivity and survivability enhancement over the TOD designs analyzed during the trade-off analysis.

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ANNEX VII TO APPENDIX N

LEVEL FLIGHT ANALYSIS - CRUISE EFFICIENCY

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ANNEX VII TO APPENDIX N
LEVEL FLIGHT ANALYSIS-CRUISE EFFICIENCY

N-VII-1. PURPOSE. This section of the level flight analysis will examine the cruise efficiencies of each candidate system relative to power required and fuel flow.

N-VII-2. BACKGROUND. The Light Helicopter Family (LHX) will use advanced technology engines which will be more efficient than current power plants.

N-VII-3. LIMITATIONS.

a. The analysis will address Scout-Attack (SCAT) and Utility candidates based on new rotorcraft designs. The new designs include a helicopter, compound helicopter, advancing blade concept (ABC), compound ABC, and a tilt rotor (TR).

b. The conditions to be examined are 4,000 feet (ft)/95° Fahrenheit (F) and 2,000 ft/70°F.

c. Comparisons to the existing fleet of Army helicopters is not within the purview of a trade-off analysis (TOA) but is the responsibility of the cost and operational effectiveness analysis (COEA).

d. Comparisons will be at the design gross weight value.

N-VII-4. METHODOLOGY.

a. The analysis is conducted using the new design helicopter as the benchmark against which all other designs will be compared. The analysis will consist of two parts. One part will compare the use of energy; i.e., power required versus airspeed for each design from which a net difference in energy level will be established over the airspeed range of 0-180 knots (kt). A limited airspeed of 180 kt is selected as it represents a realistic upper limit for the helicopter. Beyond 180 kt, the TR does not have a contender within the presently identified list of LHX candidates.

b. A second part will compare the cruise efficiency as expressed by fuel flow versus airspeed for each design from which a net difference in energy consumption will be established over the airspeed range of 0-180 kt. The trend in efficiency should be synonomous with the trend determined in the first part.

c. In both parts, the results will be related to percent difference in costs.

N-VII-5. RESULTS/ANALYSIS.

a. SCAT: 4,000 ft/95°F.

(1) Figures N-VII-1 through N-VII-4 present a graphical comparison of SCAT power required versus airspeed for the helicopter against each of the other candidate rotorcraft. The comparisons which present the helicopter versus compound helicopter, ABC, and compound ABC show the helicopter to be more efficient relative to energy requirements as a function of speed. The comparison of the helicopter and TR shows the helicopter to be more efficient up to 135 kt at which point the TR, due to nacelle programing which transforms the TR into a fixed wing system, becomes the more efficient system to the extent that at 180 kt, which represents the upper limit for the helicopter, the power required is approximately 580 horsepower less than the helicopter! Above 180 kt, the TR's energy requirement slope transcends those of the other systems.

(2) Figures N-VII-5 through N-VII-8 translate the difference in horsepower of the above figures into percent difference as a function of airspeed. Using the helicopter as a normalized base, the average difference in power requirements over the speed range of 0-180 kt is presented in table N-VII-1.

Table N-VII-1. LHX-SCAT cruise efficiency, 4,000 ft/95°F.

AVERAGE PERCENT DIFFERENCE IN POWER REQUIRED (0-180 KT)

Configuration	Percent Difference
Helicopter	0
Compound Helicopter	14.12
ABC	20.96
Compound ABC	41.36
TR	21.39

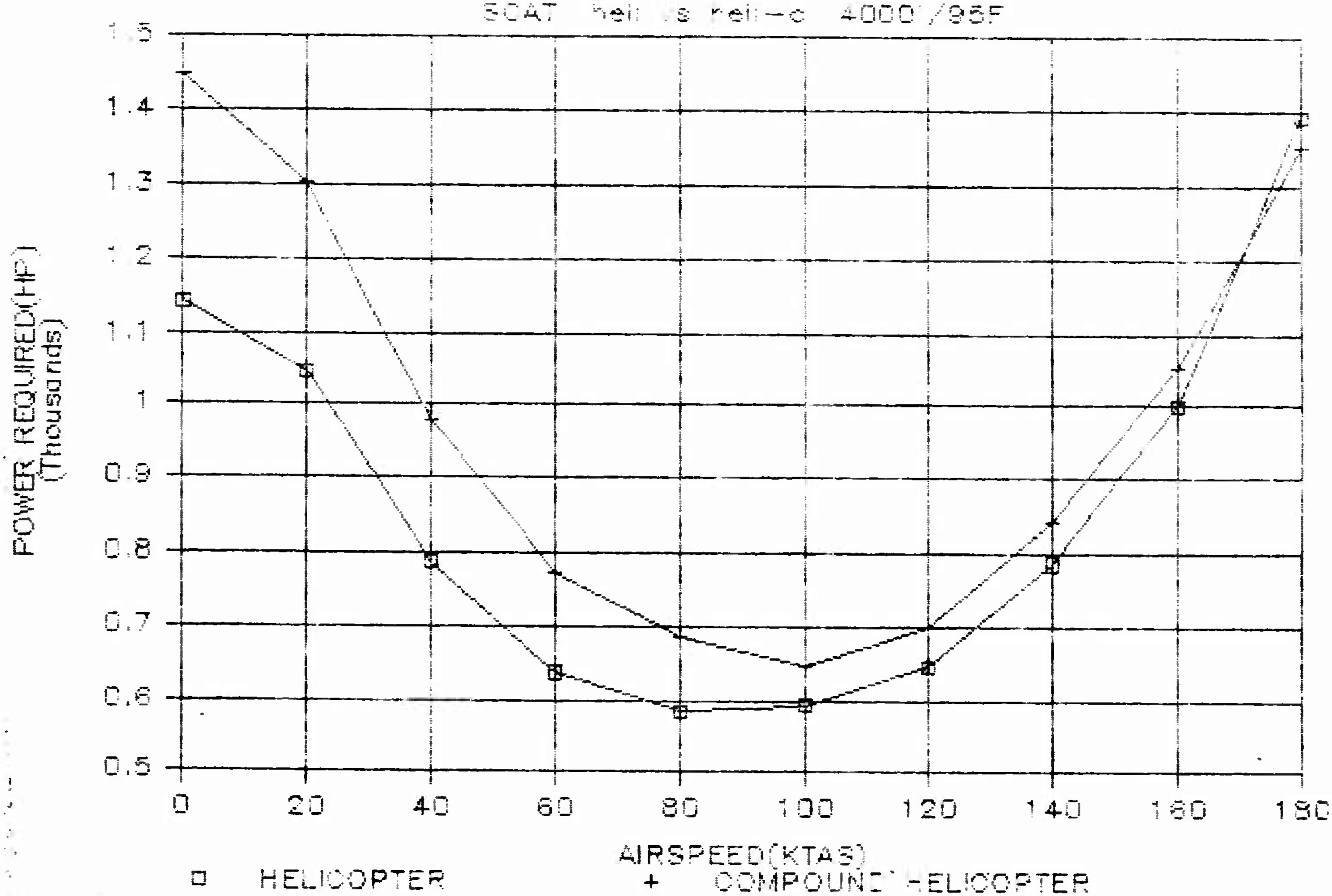

Figure N-VII-1. SCAT power required: helicopter and helicopter-compound, 4,000'/95°F.

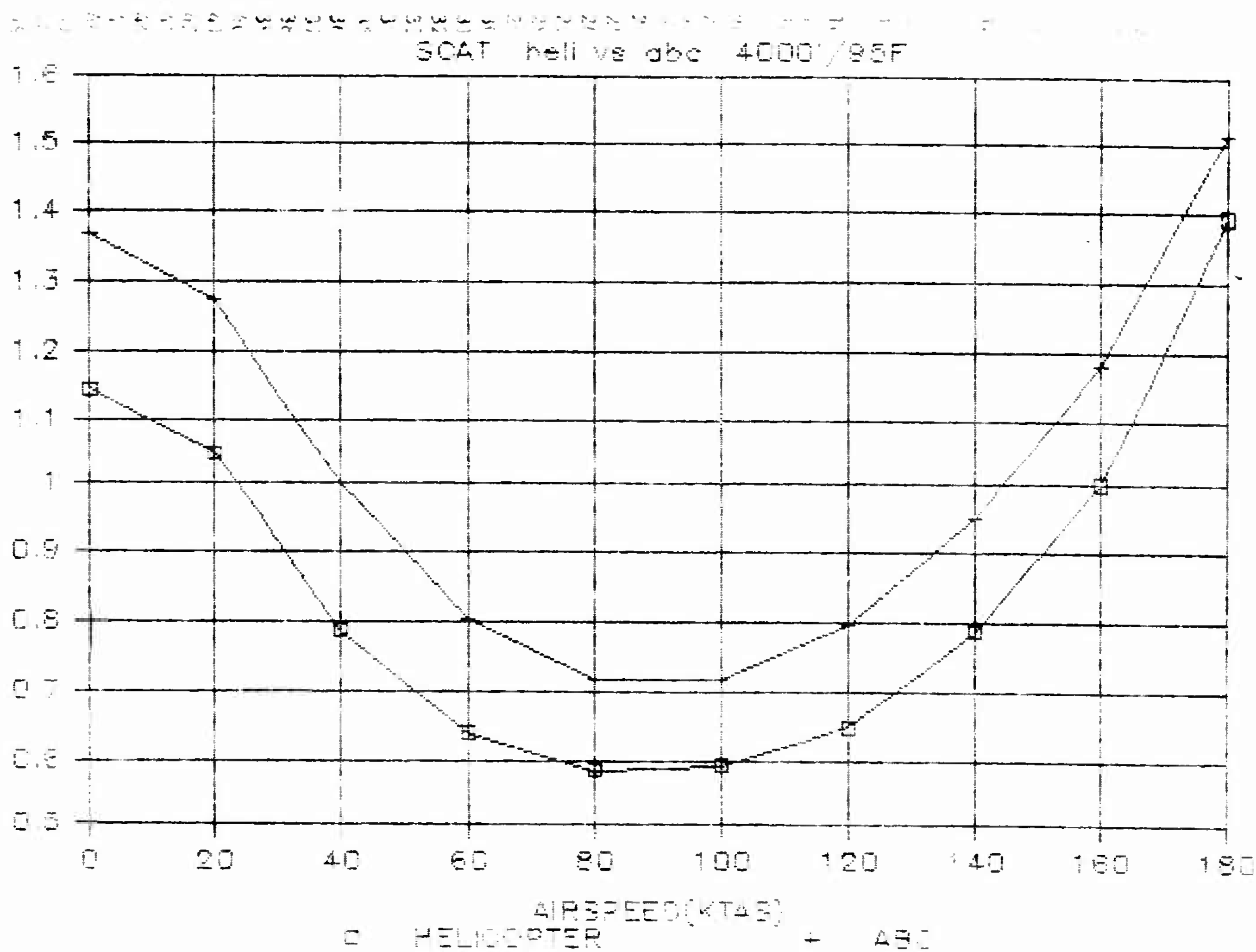

Figure N-VII-2. SCAT power required: helicopter and ABC, 4,000'/95°F.

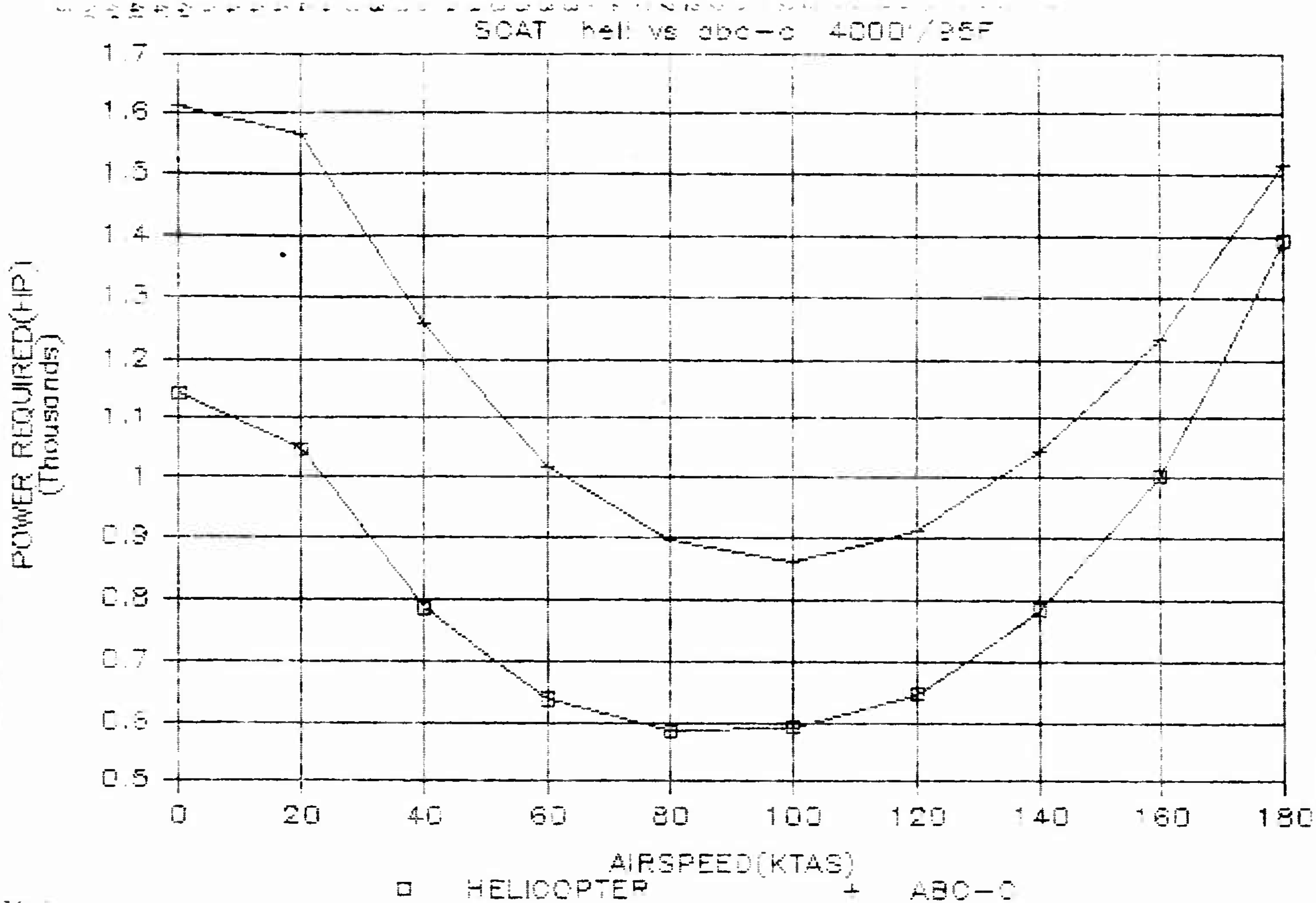

Figure N-VII-3. SCAT power required: helicopter and ABC-compound, 4,000'/95°F.

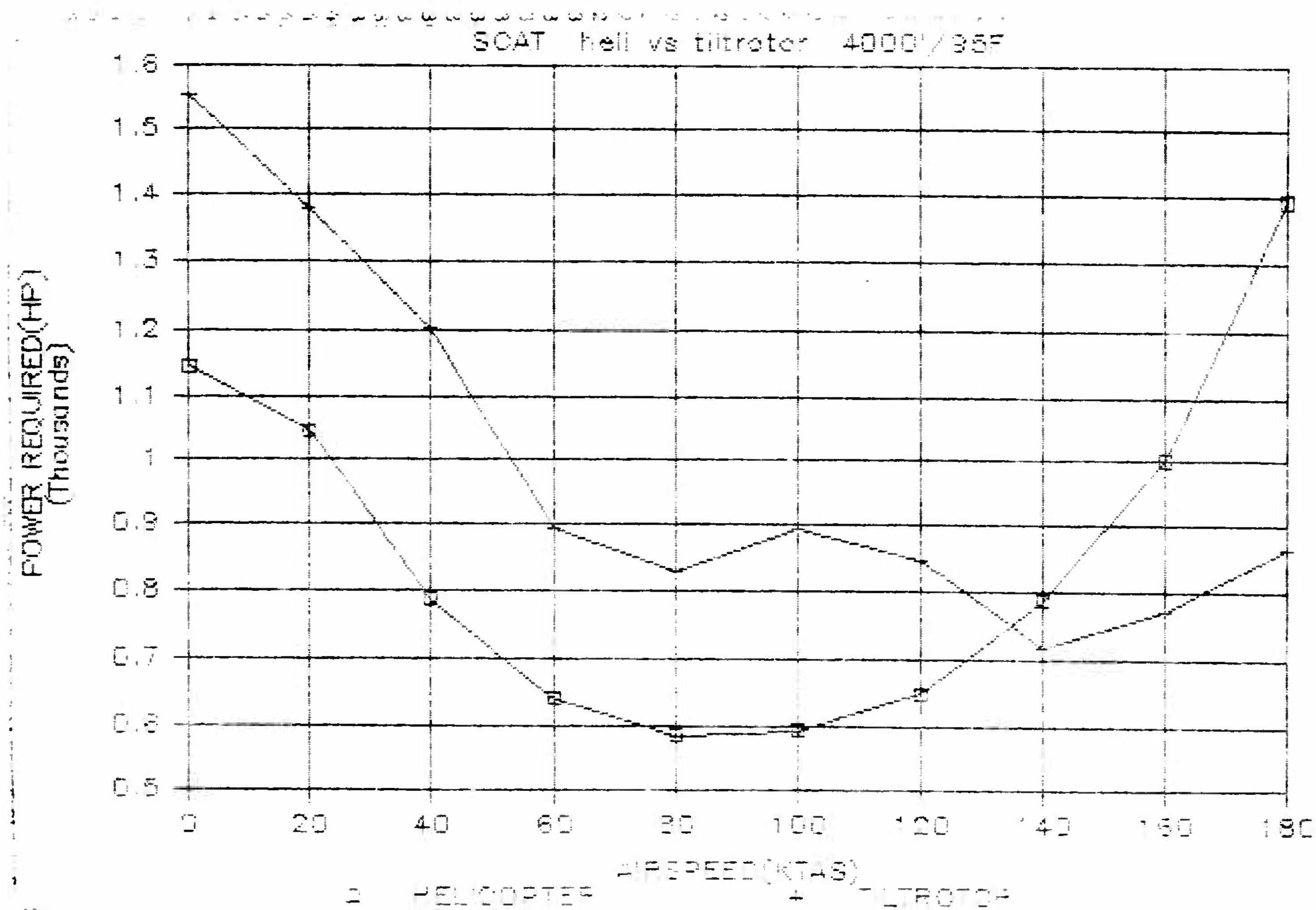

Figure N-VII-4. SCAT power required: helicopter and tilt rotor, 4,000'/95°F.

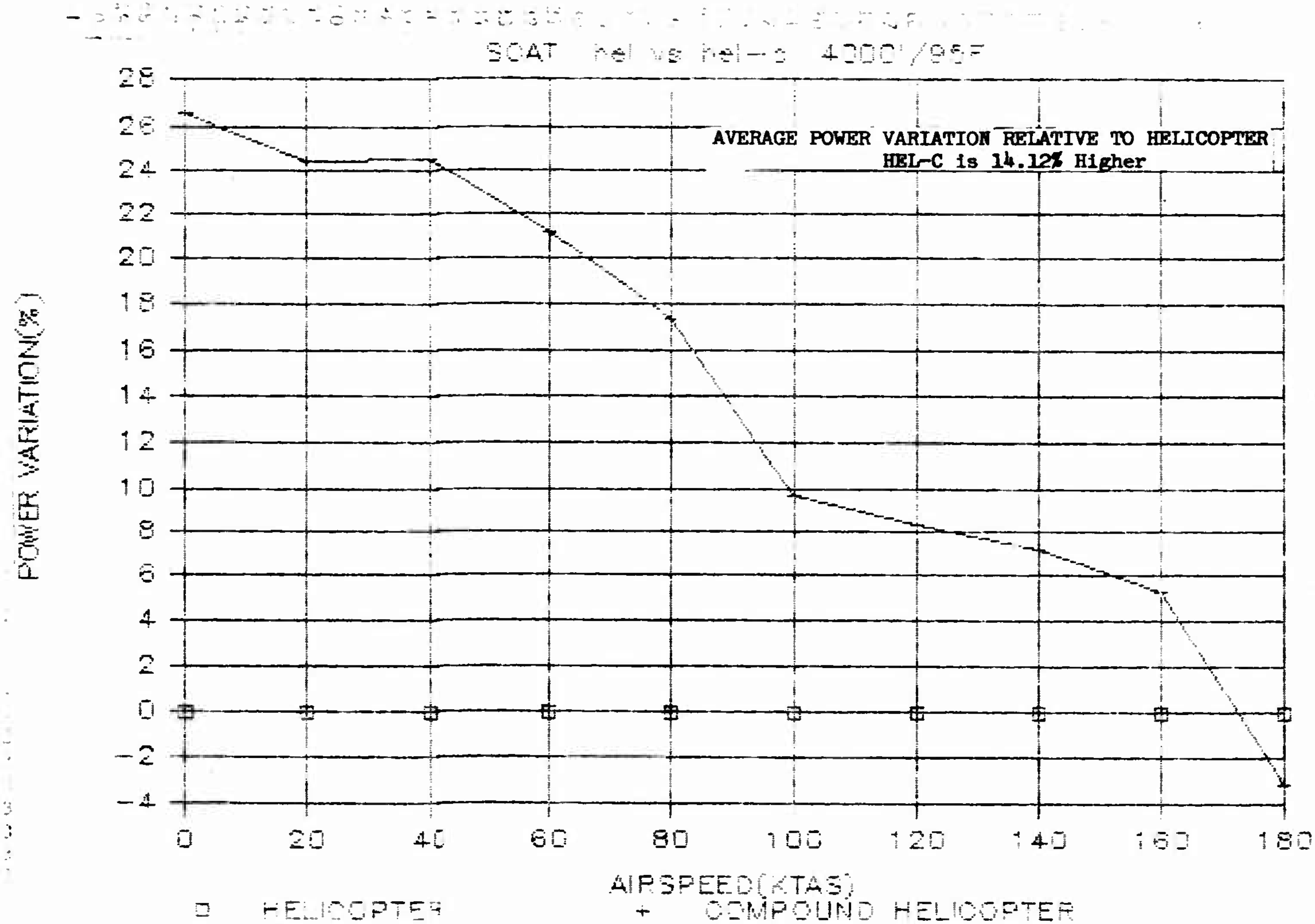

Figure N-VII-5. SCAT power variation: helicopter and helicopter-compound, 4,000'/95°F.

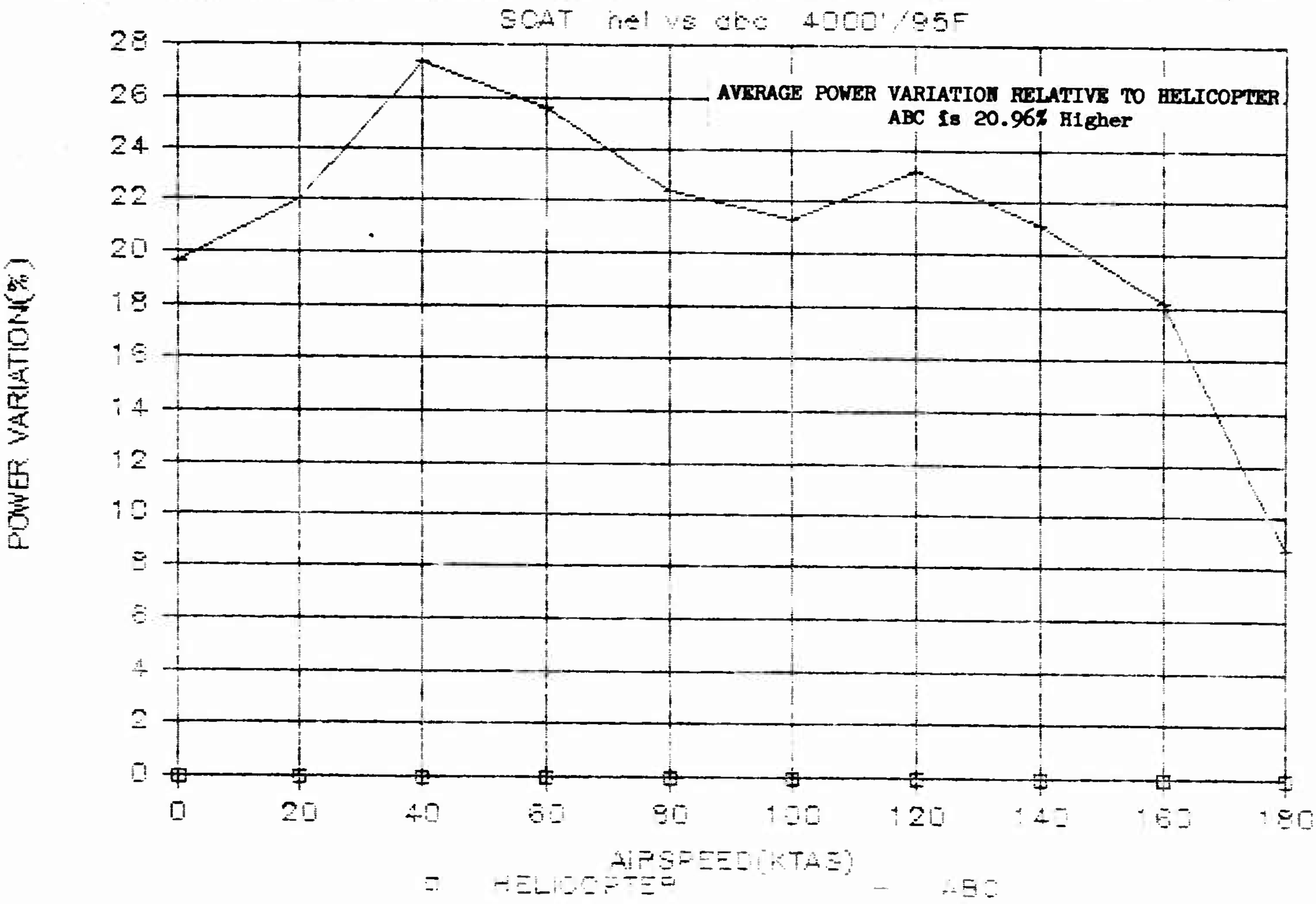

Figure N-VII-6. SCAT power variation: helicopter and ABC, 4,000'/95°F.

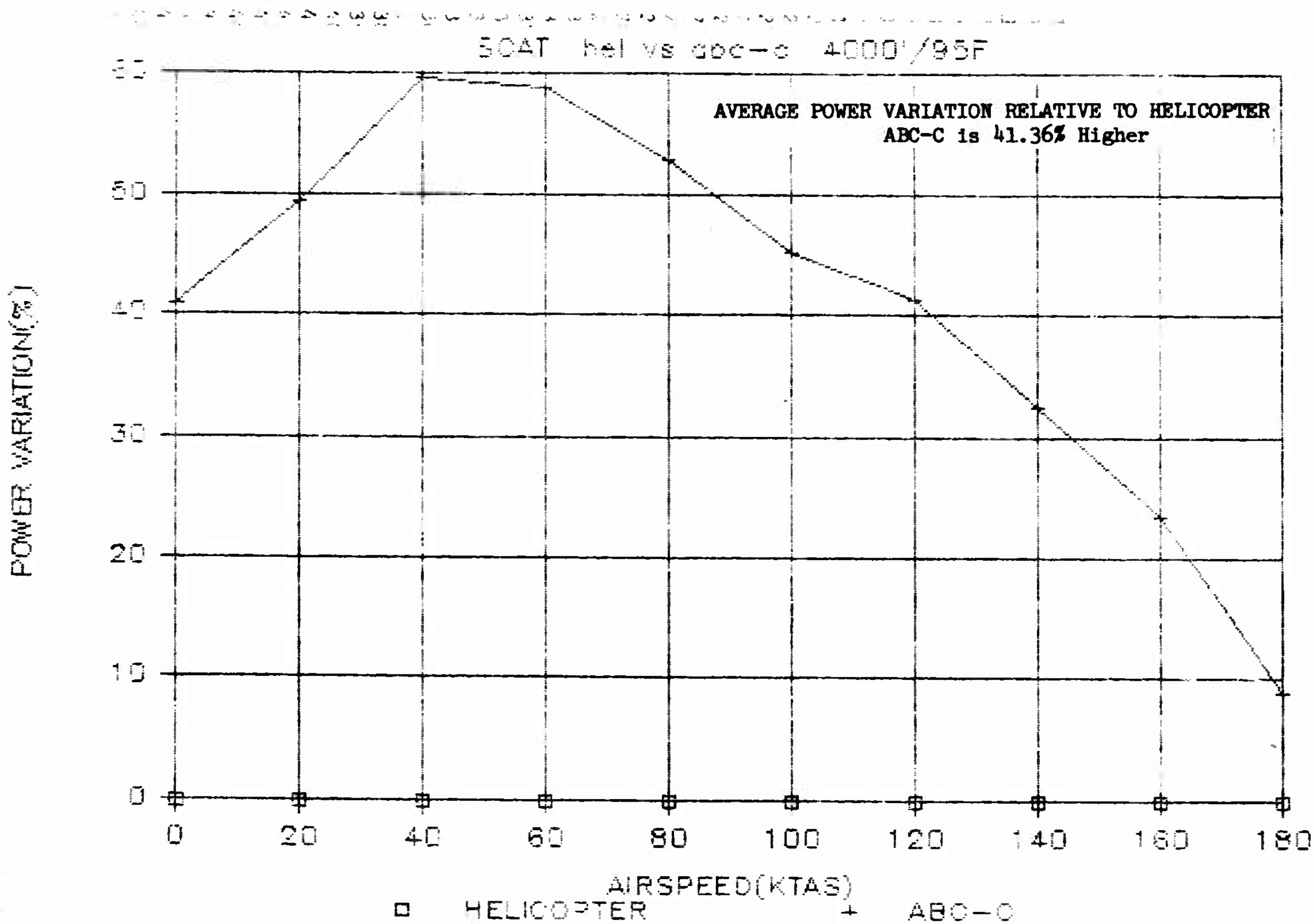

Figure N-VII-7. SCAT power variation: helicopter and ABC-compound, 4,000'/95°F.

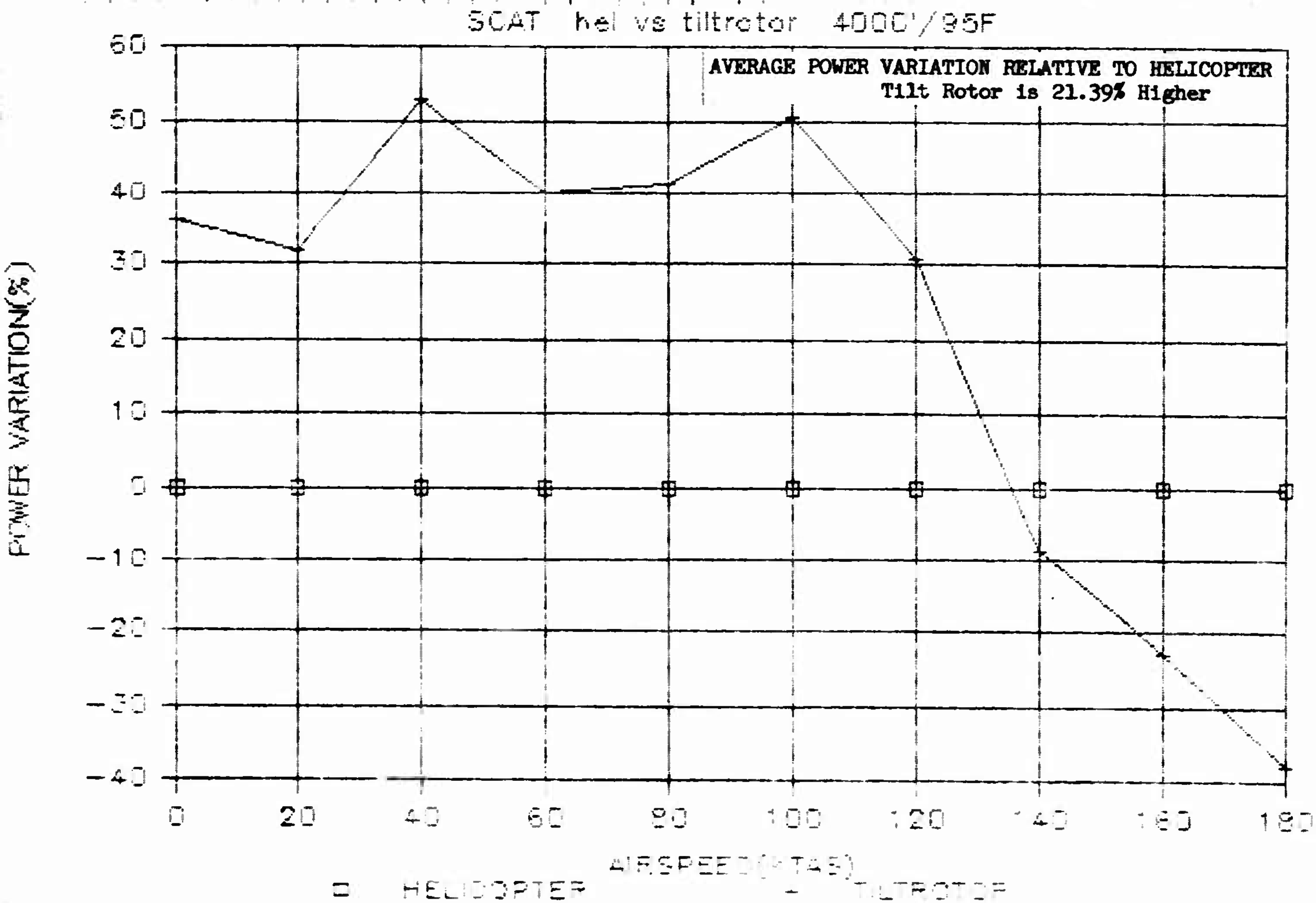

Figure N-VII-3. SCAT power variation: helicopter and tilt rotor, 4,000'/95°F.

(3) Figures N-VII-9 through N-VII-12 show the fuel flow comparisons that correspond to the power requirements shown by figures N-VII-1 through N-VII-4. As expected, this data parallels the power required figures; i.e., fuel flow is higher versus helicopter with the TR showing a crossover at approximately 145 kt. It is noted that the helicopter:TR crossover should have occurred at 135 kt but typical accuracies of the design programs cause seeming anomalies. A breakout of the percent difference in fuel flow for each is shown in figures N-VII-13 through N-VII-16. Using the helicopter as a normalized base, the average difference in fuel flow is presented in table N-VII-2.

Table N-VII-2. LHX-SCAT cruise efficiency, 4,000 ft/95°F.

AVERAGE PERCENT DIFFERENCE IN FUEL FLOW (0-180 KT)

Configuration	Percent Difference
Helicopter	0
Compound Helicopter	15.38
ABC	18.67
Compound ABC	37.78
TR	22.79

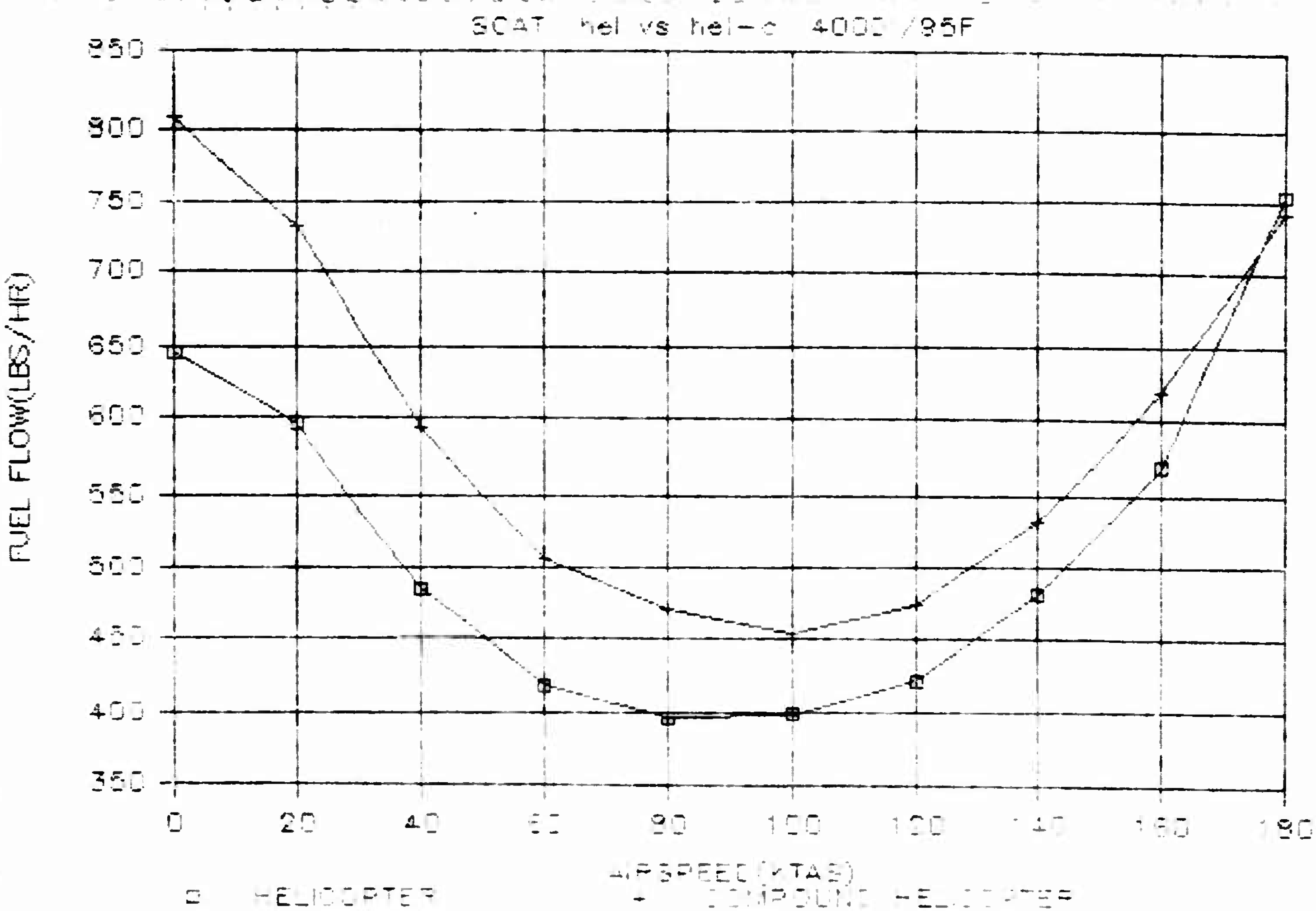

Figure N-VII-9. SCAT fuel flow: helicopter and helicopter-compound, 4,000'/95°F.

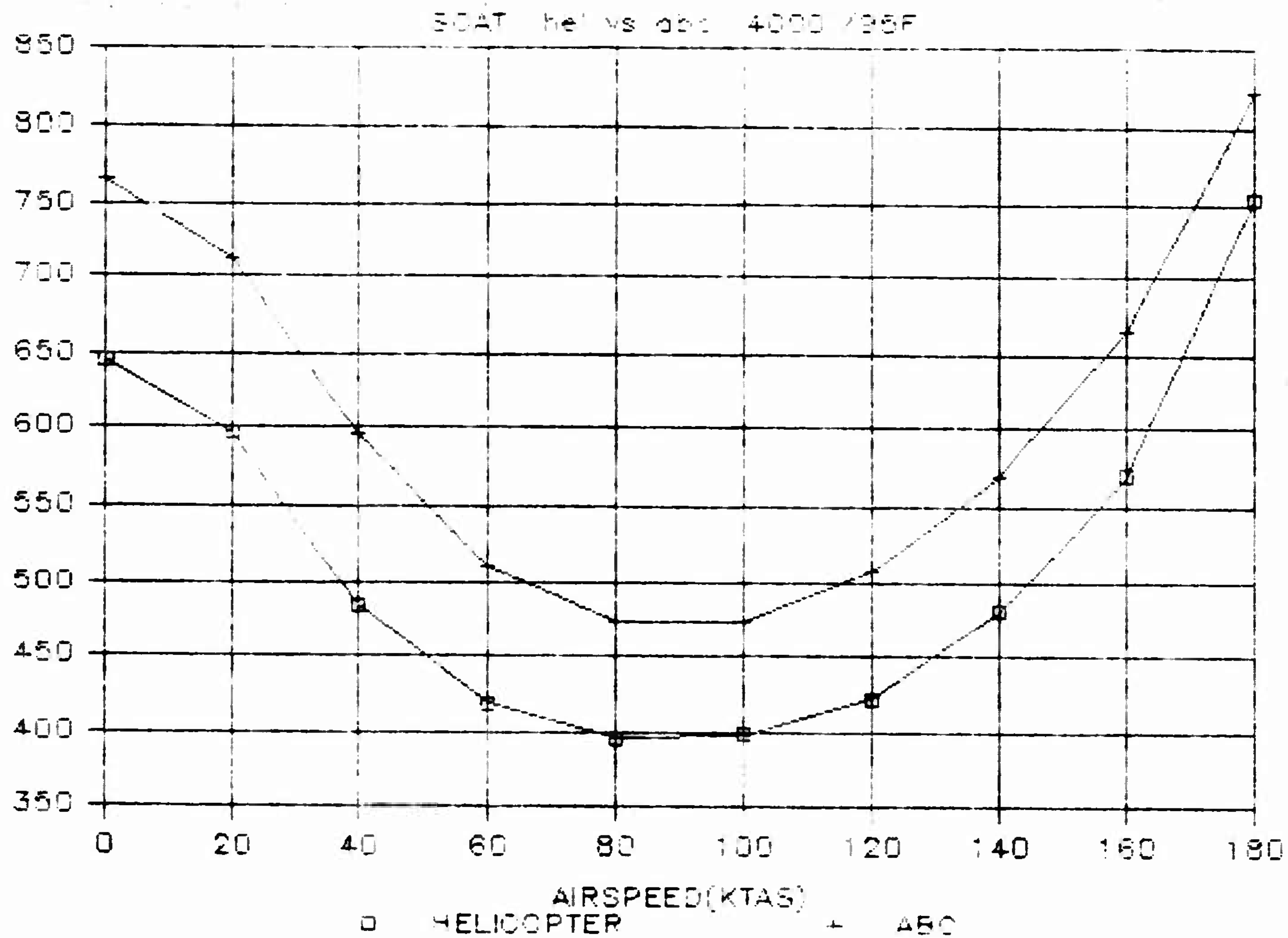

Figure N-VII-10. SCAT fuel flow: helicopter and ABC, 4,000'/95°F.

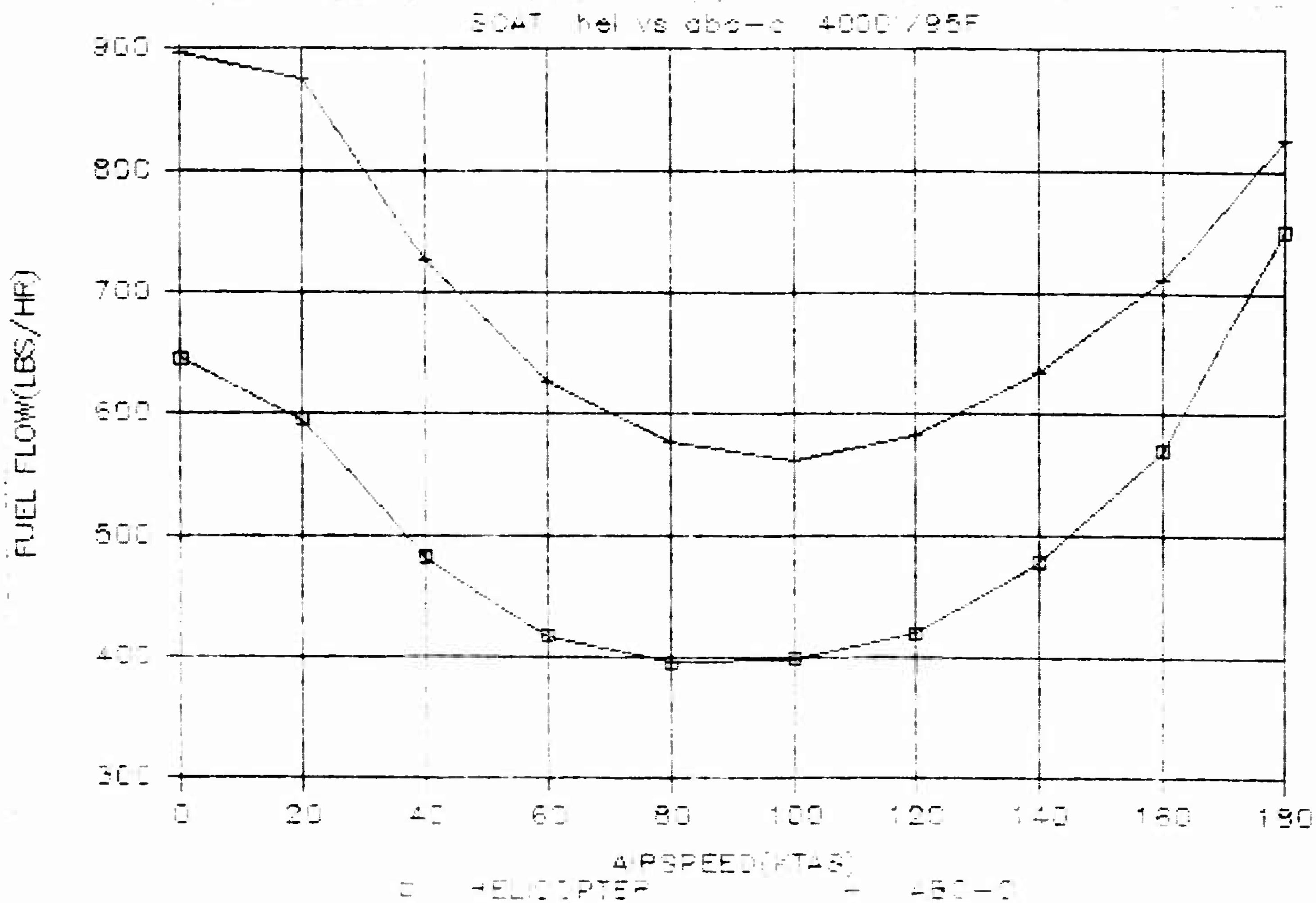

Figure N-VII-11. SCAT fuel flow: helicopter and ABC-compound, 4,000'/95°F.

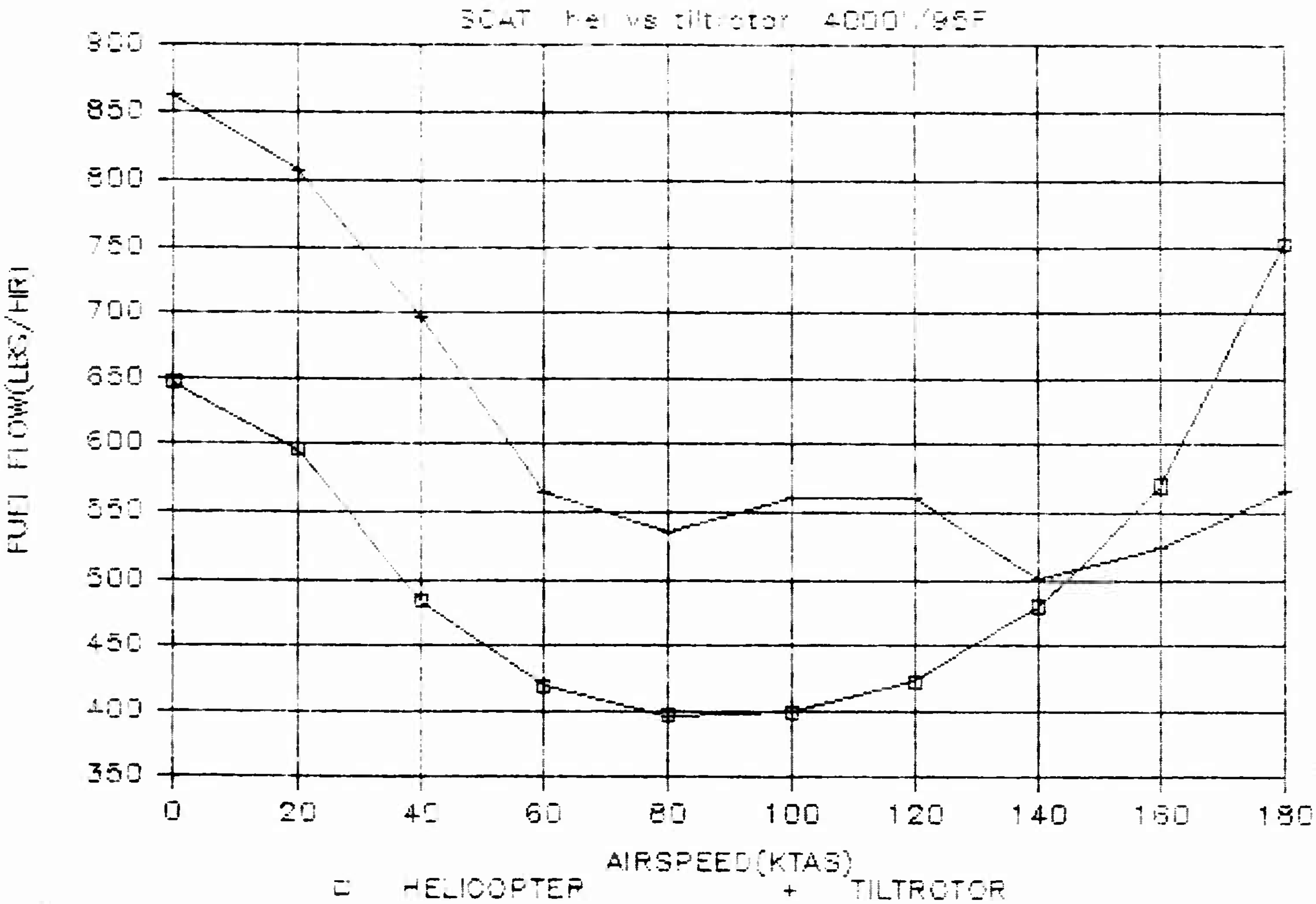

Figure N-VII-12. SCAT fuel flow: helicopter and tilt rotor, 4,000'/95°F.

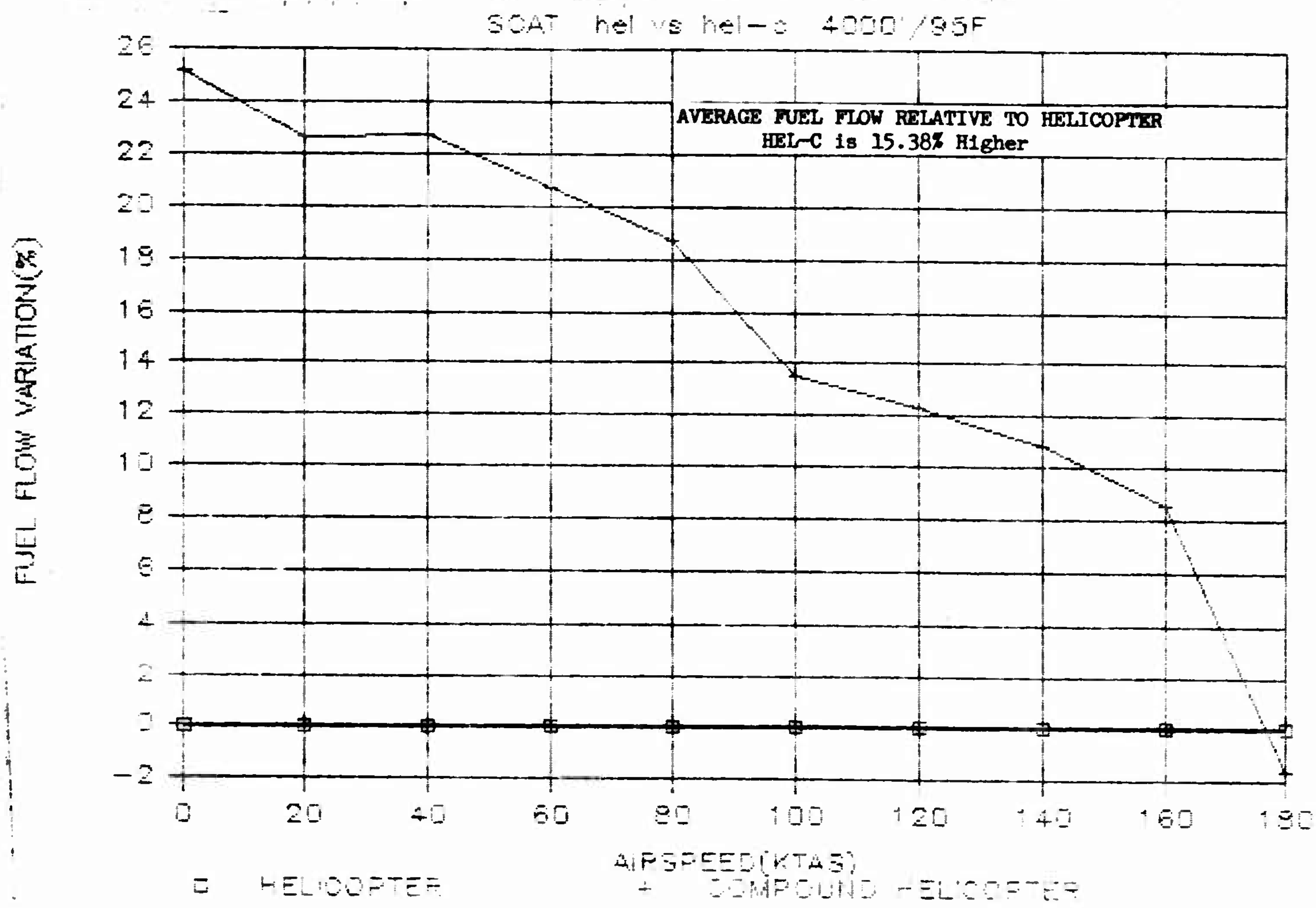

Figure N-VII-13. SCAT fuel flow variation: helicopter and helicopter-compound, 4,000'/95°F.

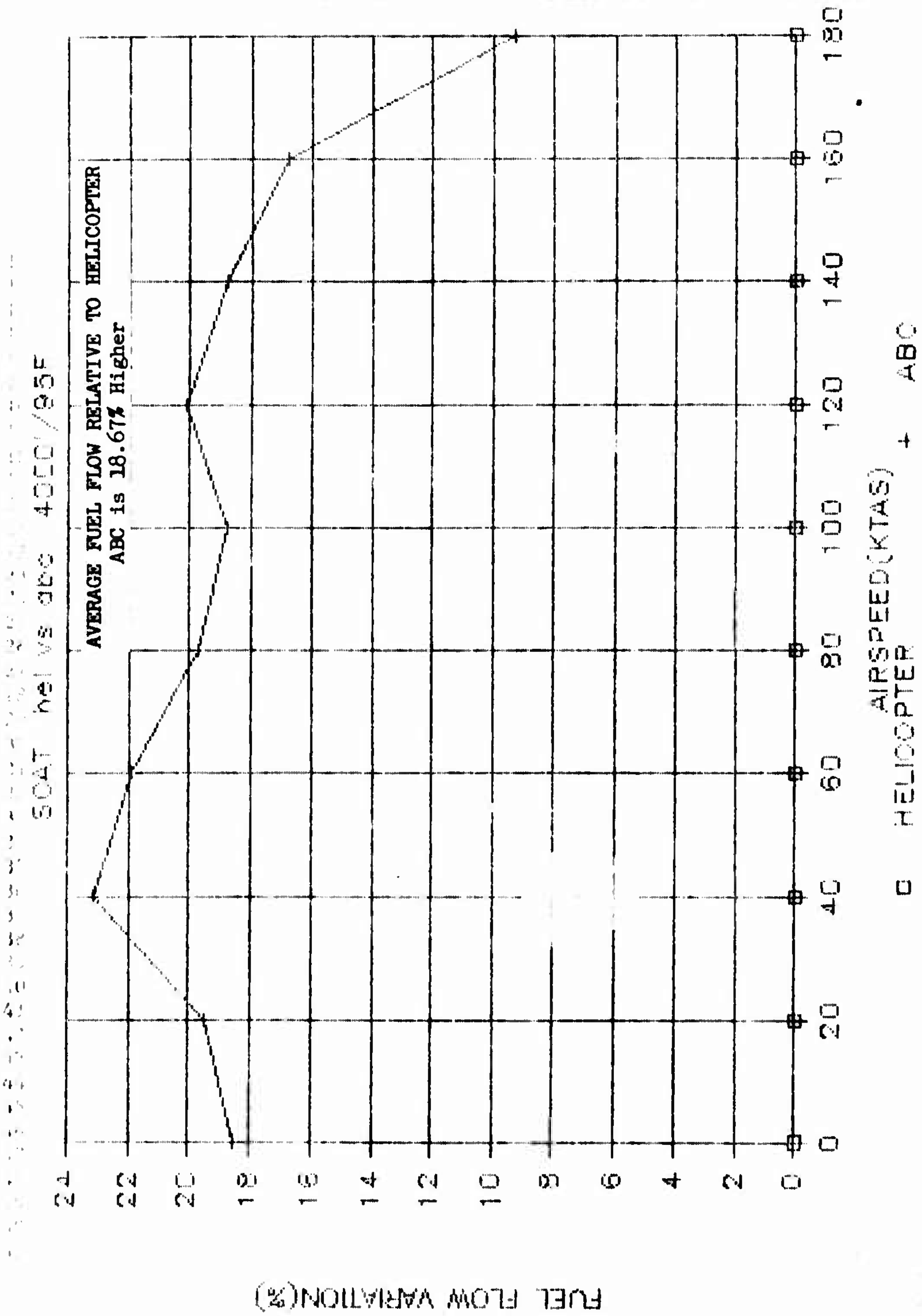

Figure N-VII-14. SCAT fuel flow variation: helicopter and ABC, 4,000'/95°F.

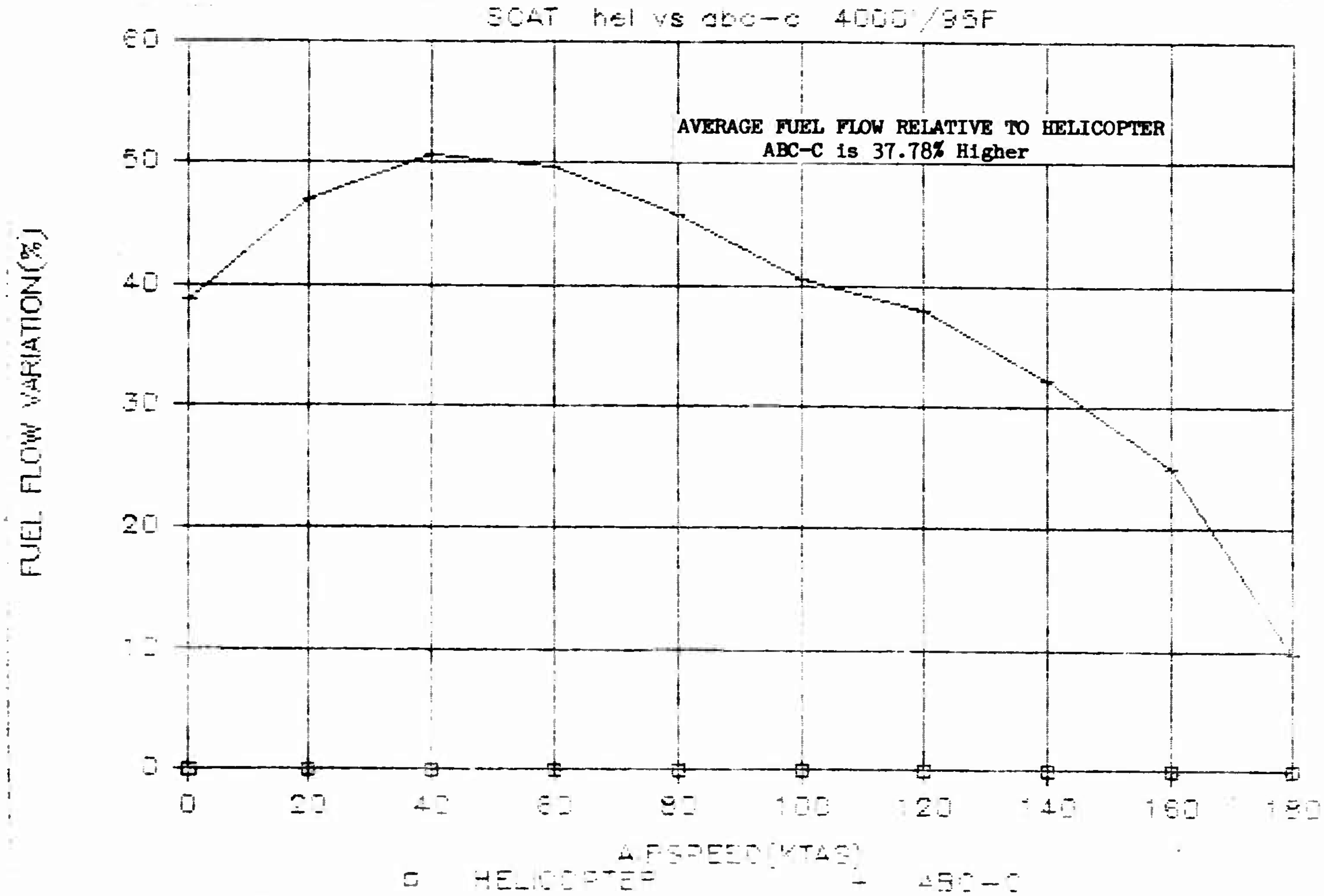

Figure N-VII-15. SCAT fuel flow variation: helicopter and ABC-compound, 4,000'/95°F.

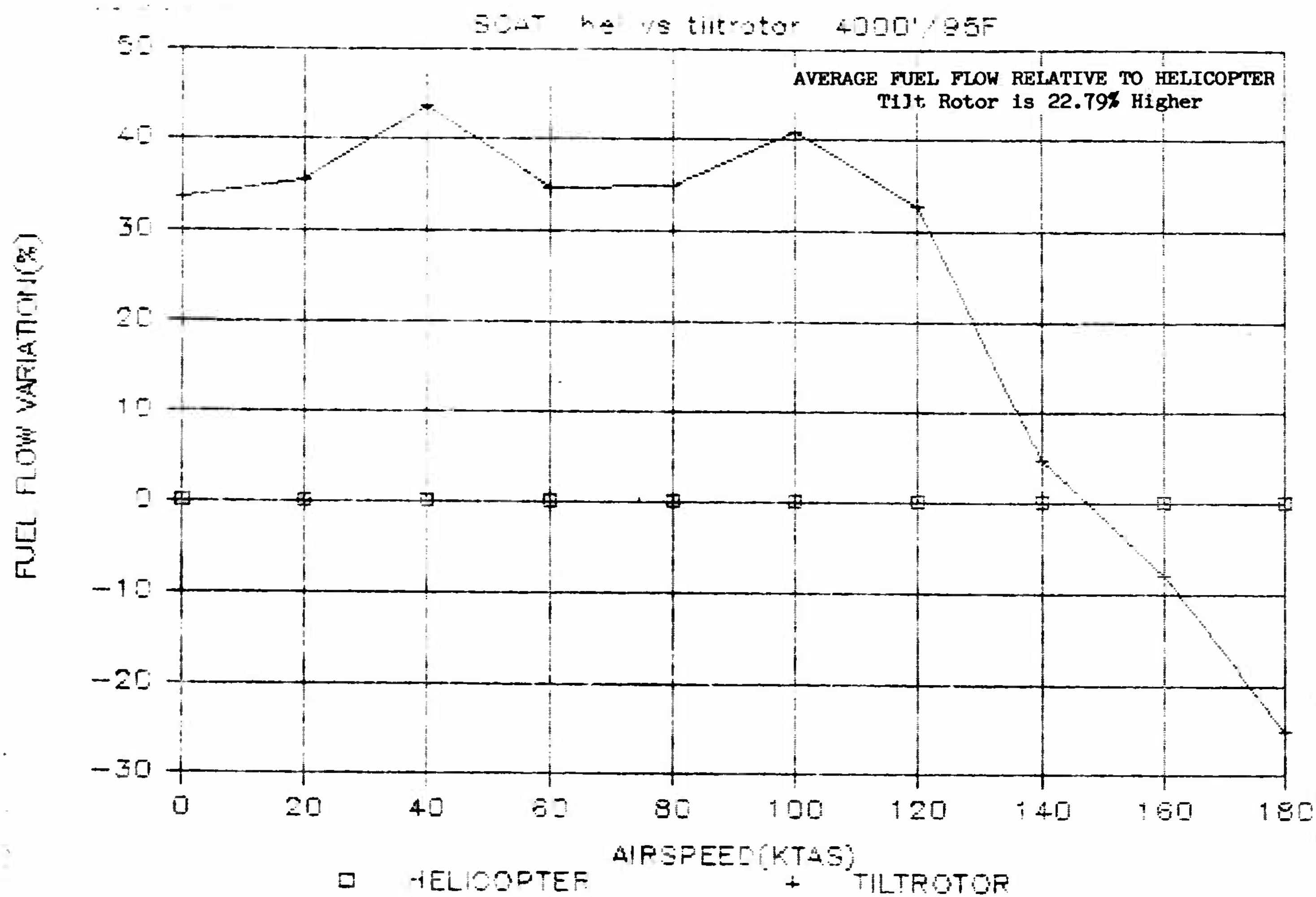

Figure N-VII-16. SCAT fuel flow variation: helicopter and tilt rotor, 4,000'/95°F.

b. Utility: 4,000 ft/95°F. Figures N-VII-17 through N-VII-20 present the power required relationships for the Utility designs. The corresponding power variations are presented in figures N-VII-21 through N-VII-24. The fuel flow relationships are presented in figures N-VII-25 through N-VII-28 with corresponding fuel flow variations presented in figures N-VII-29 through N-VII-32. The relationships noted in the SCAT comparisons also exist with the Utility designs. The average variations are presented in tables N-VII-3 and N-VII-4.

Table N-VII-3. LHX-SCAT cruise efficiency, 4,000 ft/95°F.

AVERAGE PERCENT DIFFERENCE IN POWER REQUIRED (0-180 KT)

Configuration	Percent Difference
Helicopter	0
Compound Helicopter	9.47
ABC	18.03
Compound ABC	37.76
TR	13.81

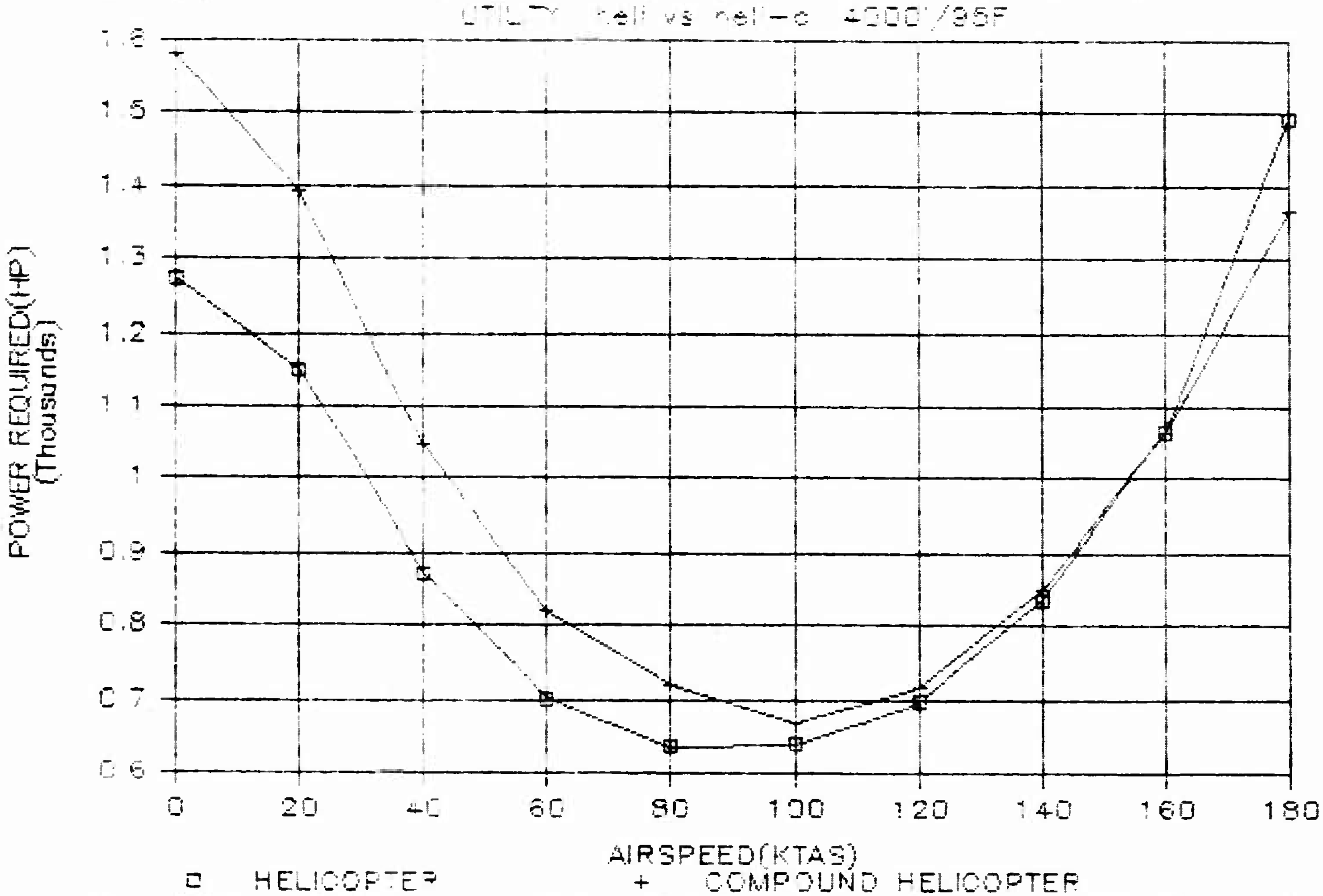

Figure N-VII-17. Utility power required: helicopter and helicopter-compound, 4,000'/95°F.

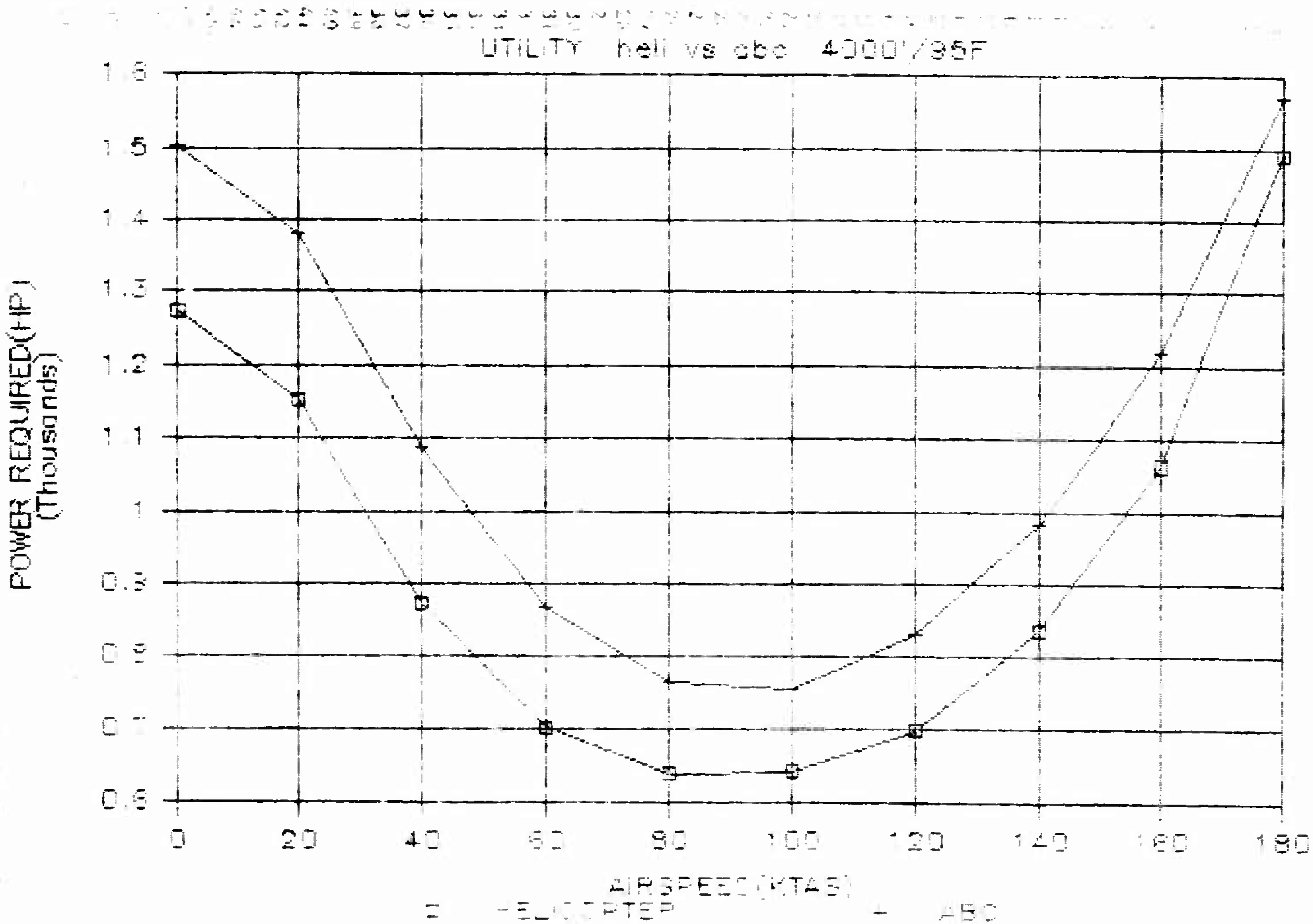

Figure N-VII-18. Utility power required: helicopter and ABC, 4,000'/95°F.

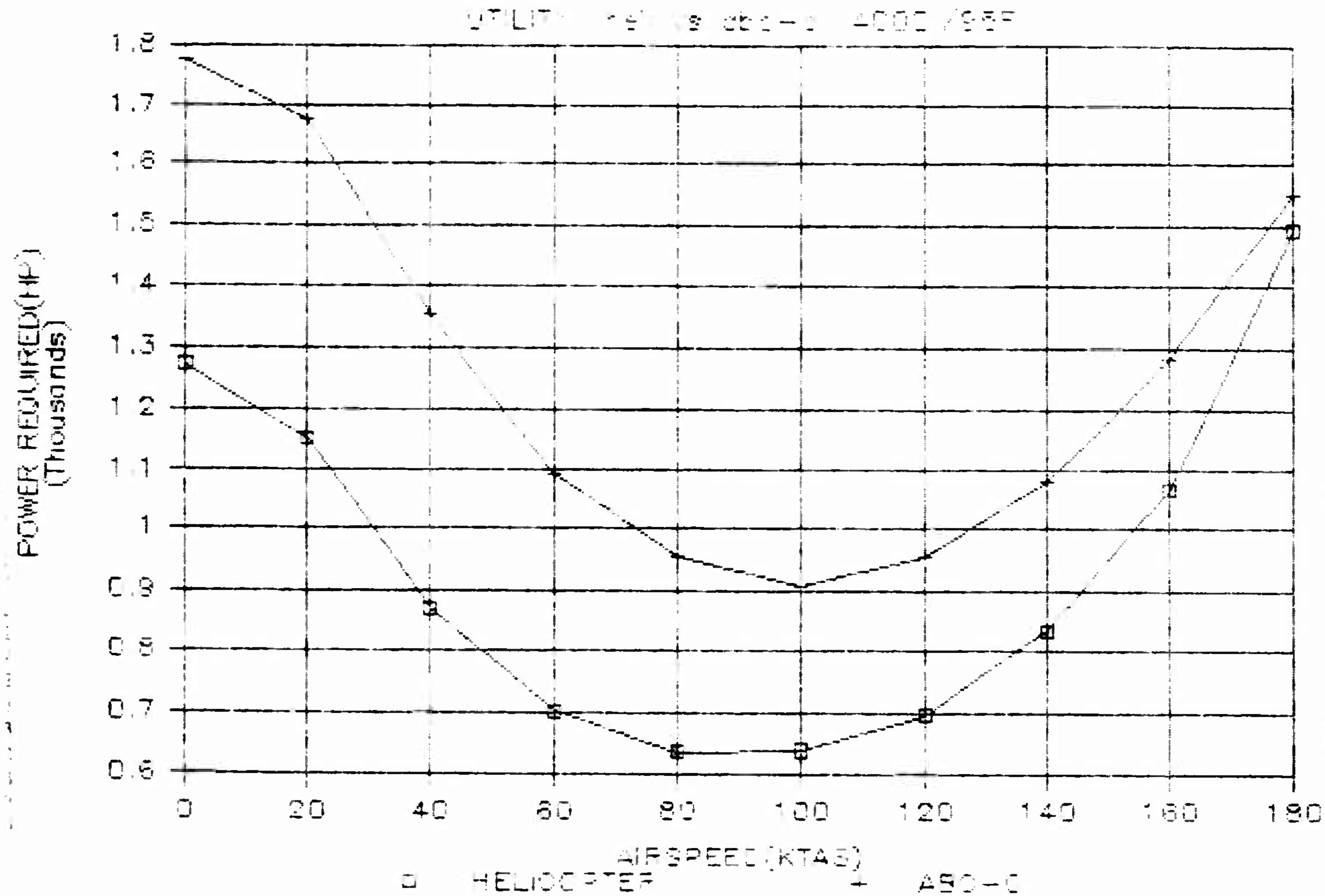

Figure N-VII-19. Utility power required: helicopter and ABC-compound, 4,000'/95°F.

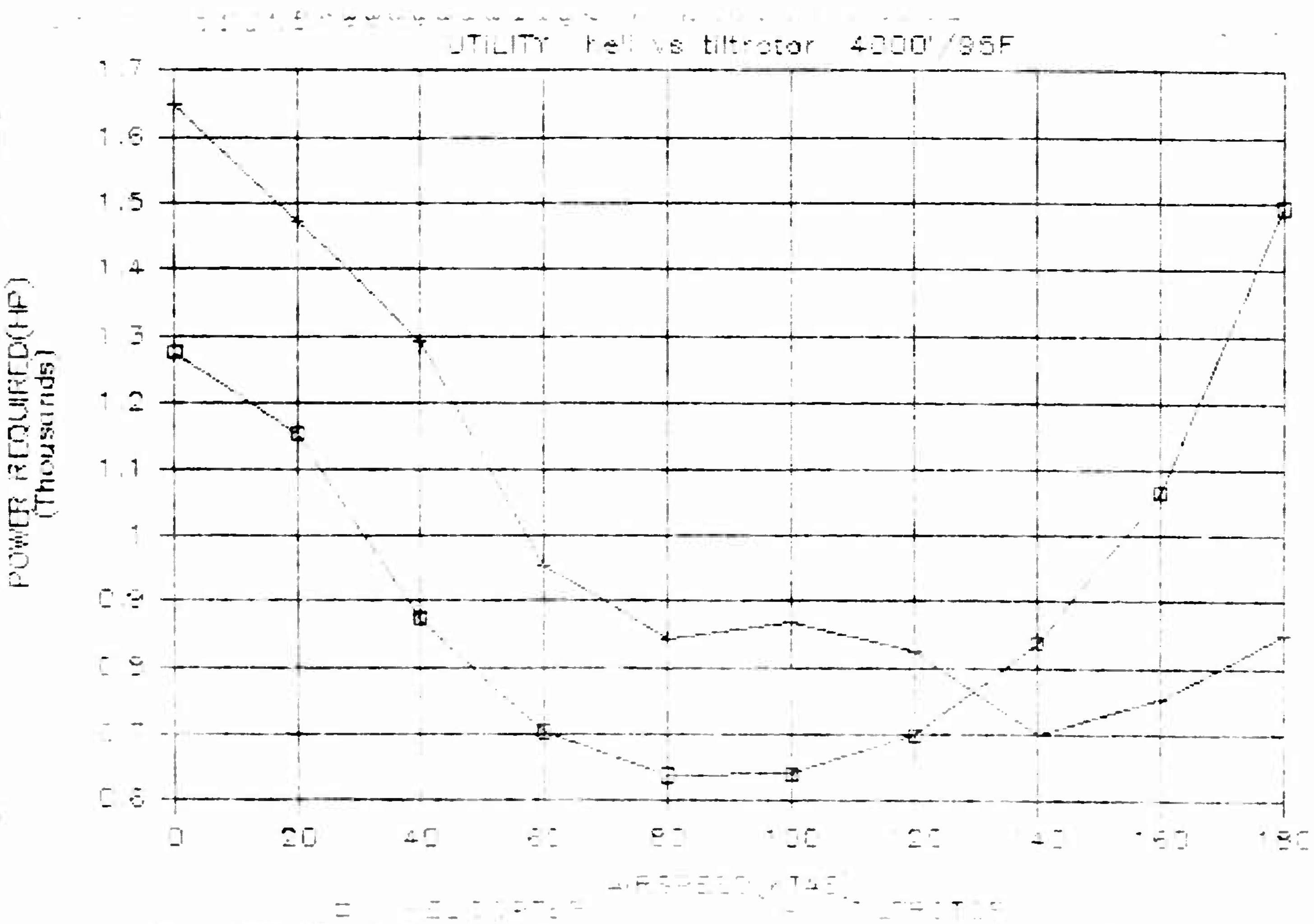

Figure N-VII-20. Utility power required: helicopter and tilt rotor, 4,000'/95°F.

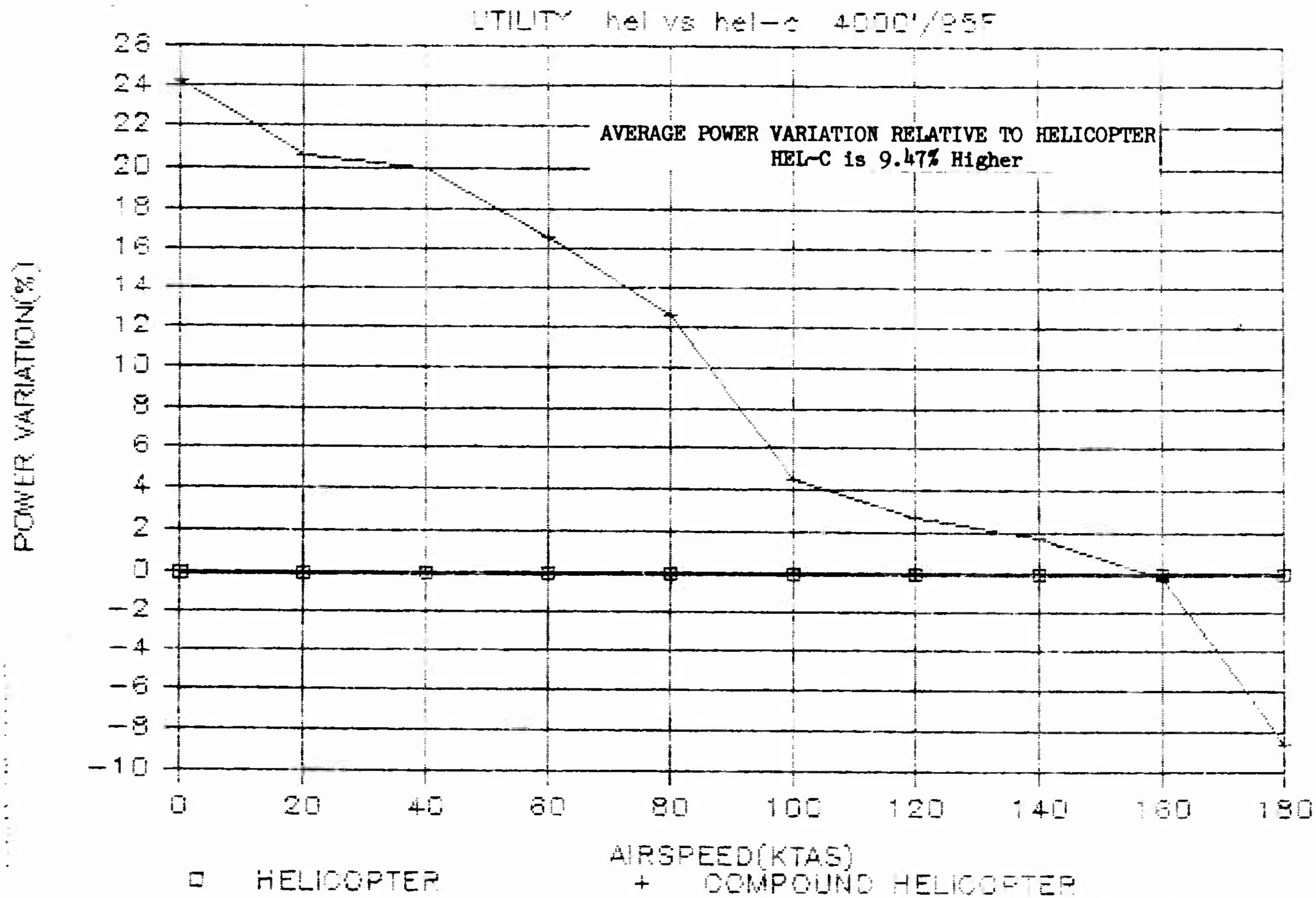

Figure N-VII-21. Utility power variation: helicopter and helicopter-compound, 4,000'/95°F.

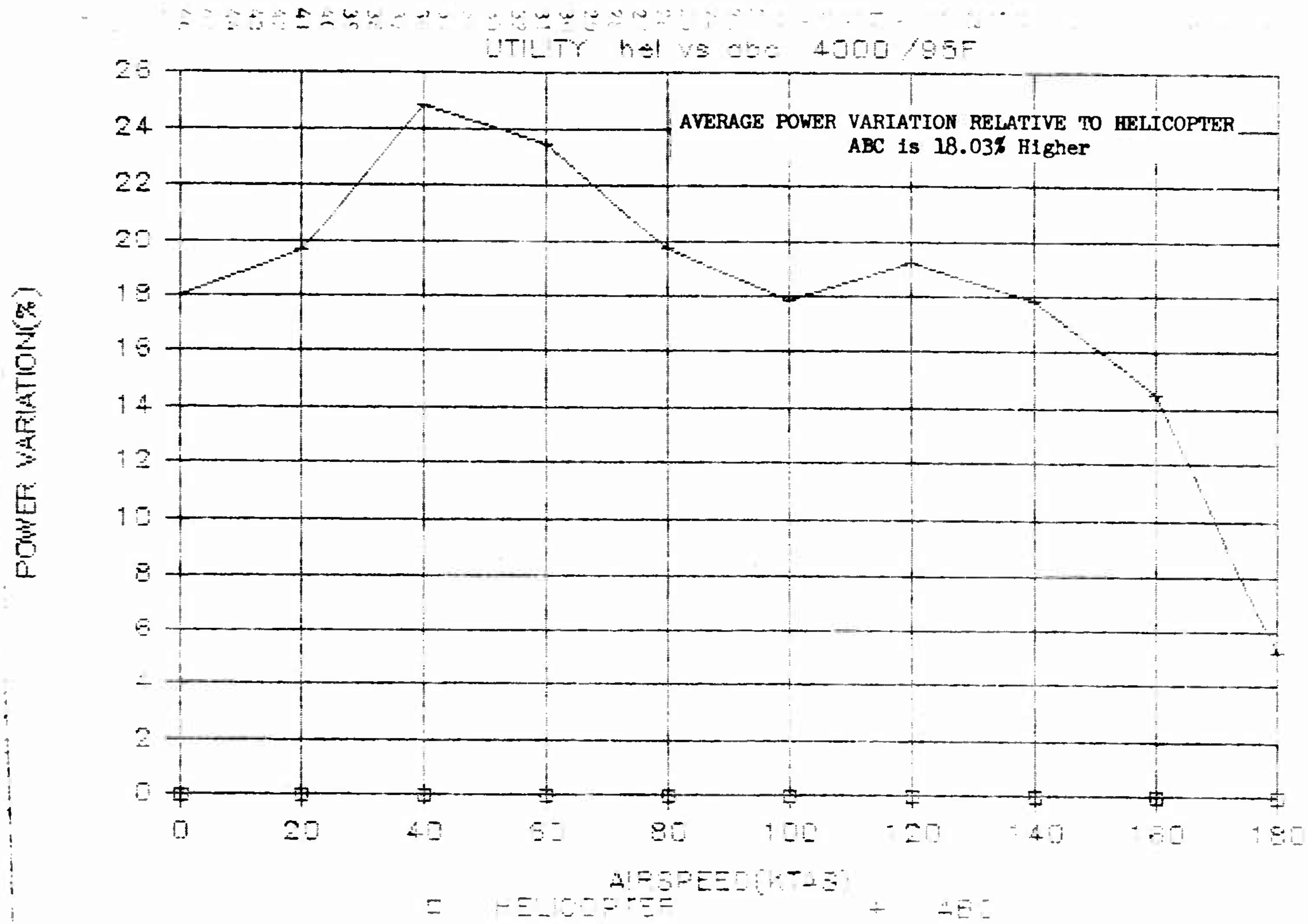

Figure N-VII-22. Utility power variation: helicopter and ABC, 4,000'/95°F.

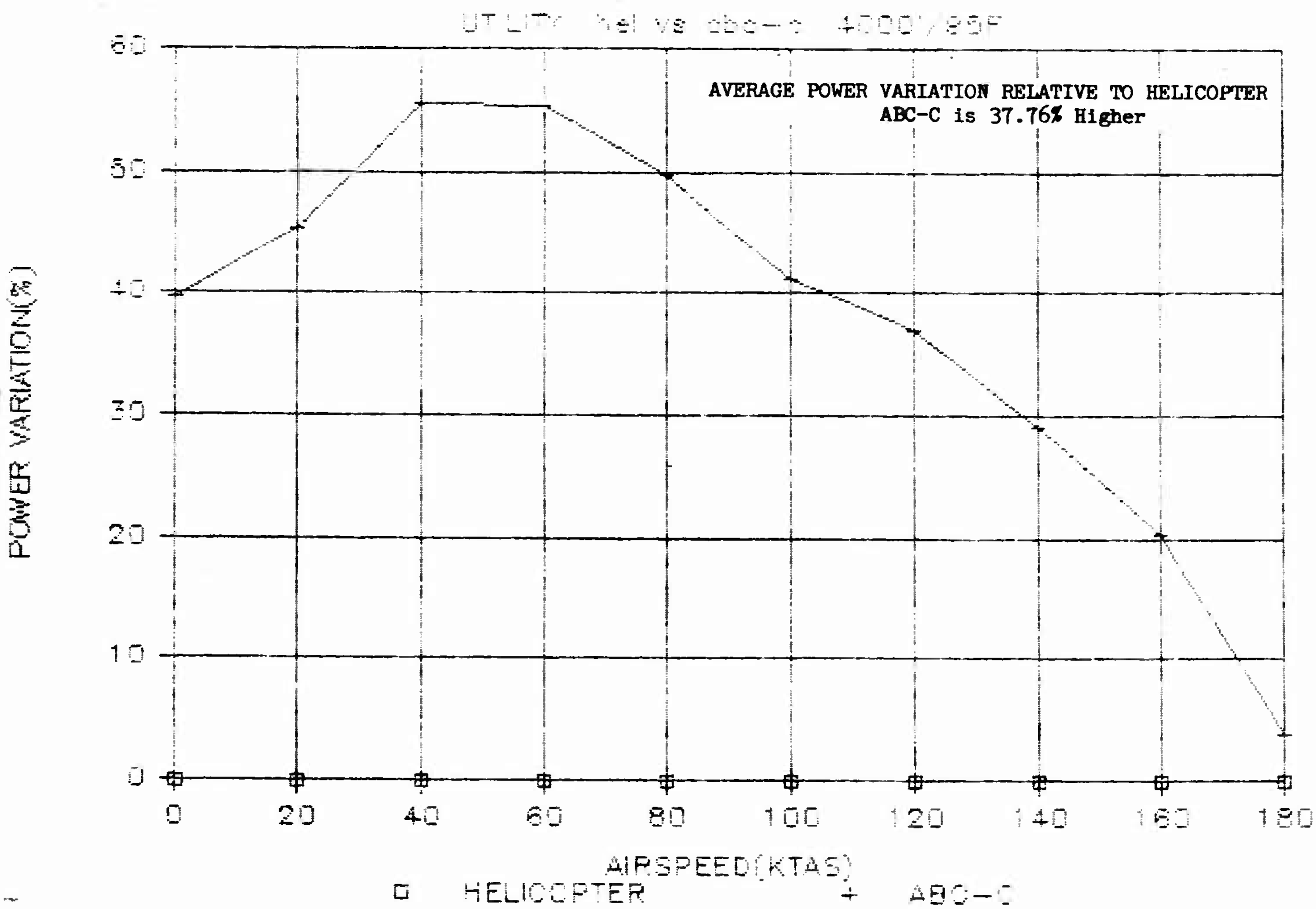

Figure N-VII-23. Utility power variation: helicopter and ABC-compound, 4,000'/95°F.

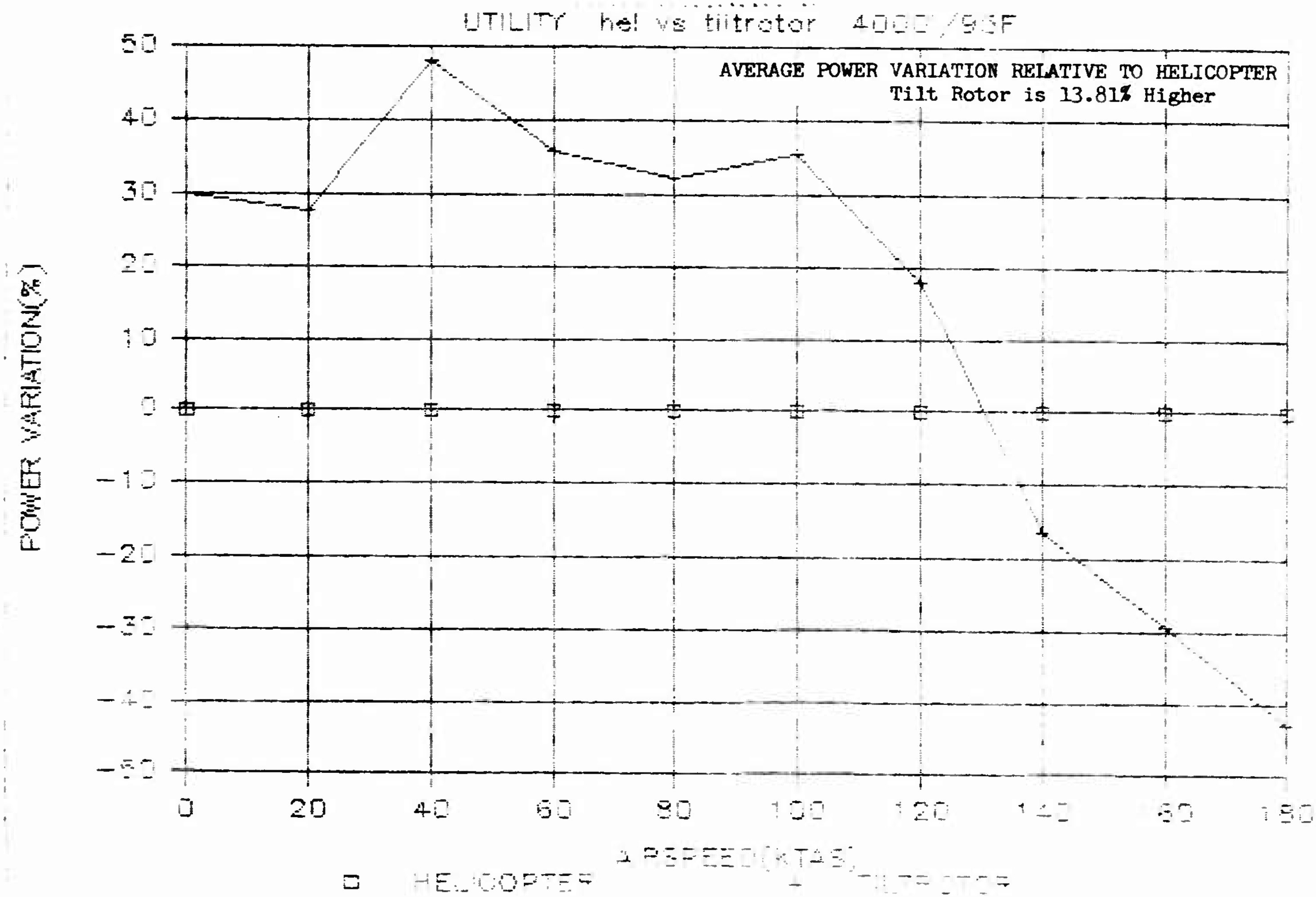

Figure N-VII-24. Utility power variation: helicopter and tilt rotor, 4,000'/95°F.

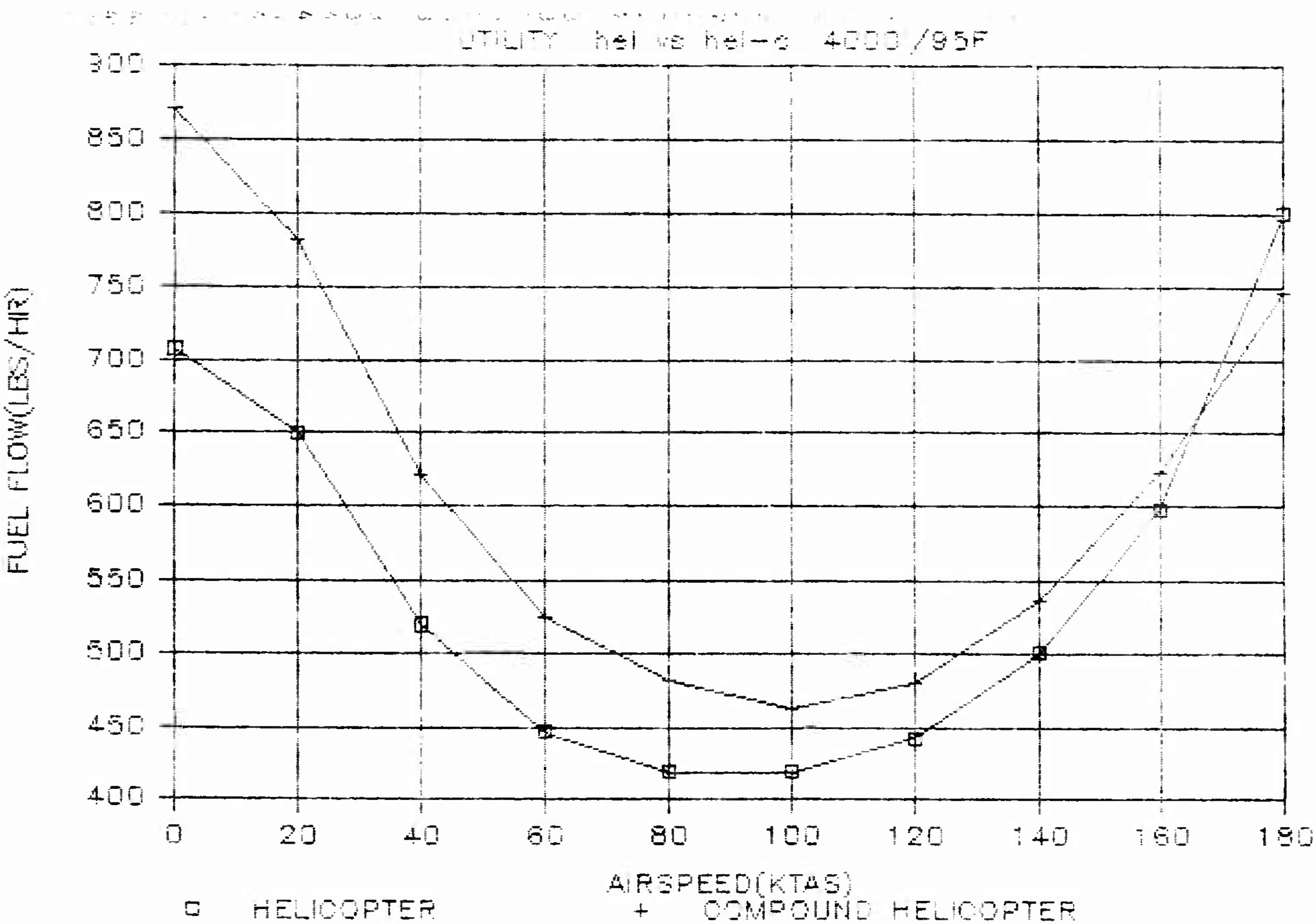

Figure N-VII-25. Utility fuel flow: helicopter and helicopter-compound, 4,000'/95°F.

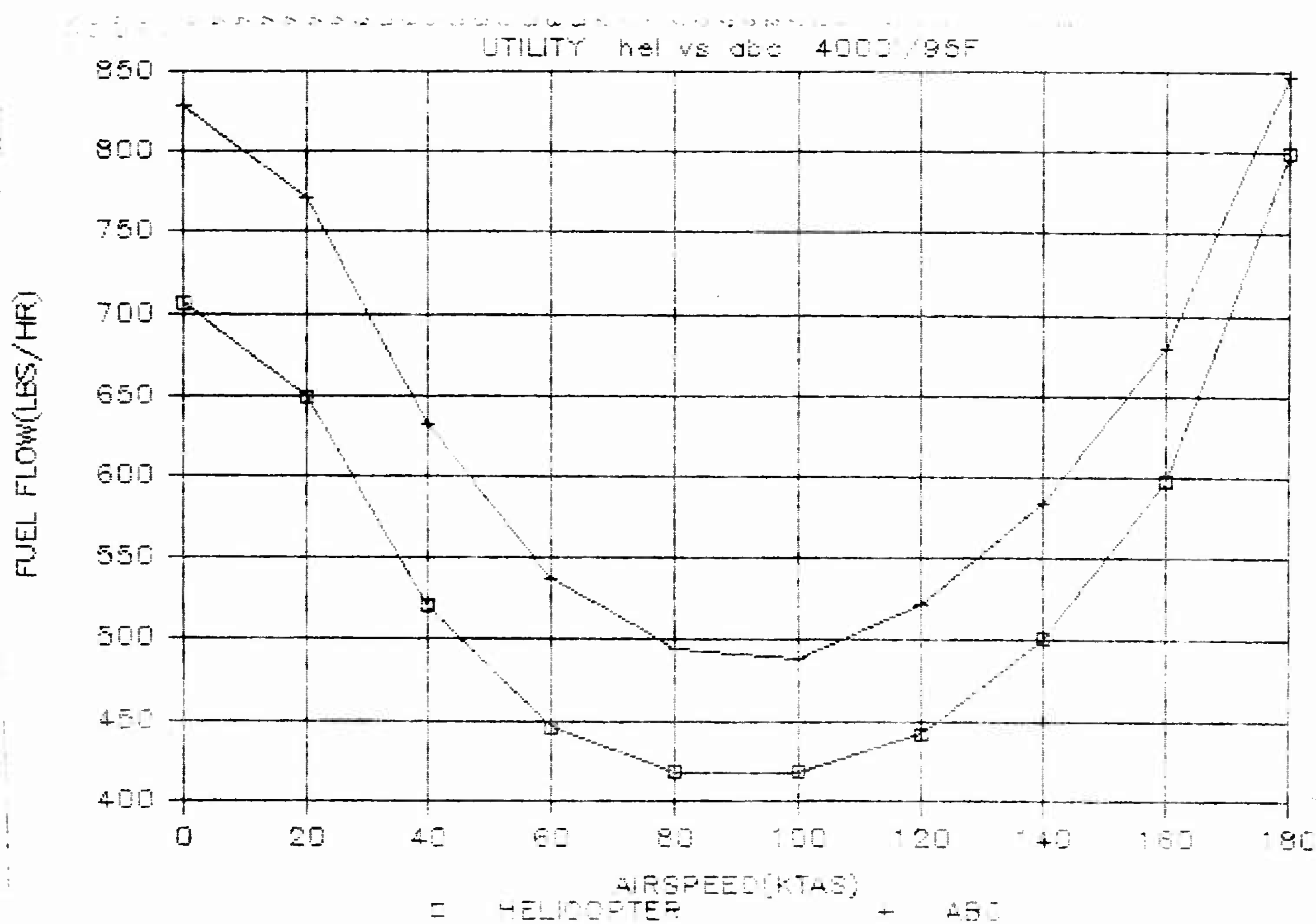

Figure N-VII-26. Utility fuel flow: helicopter and ABC, 4,000'/95°F.

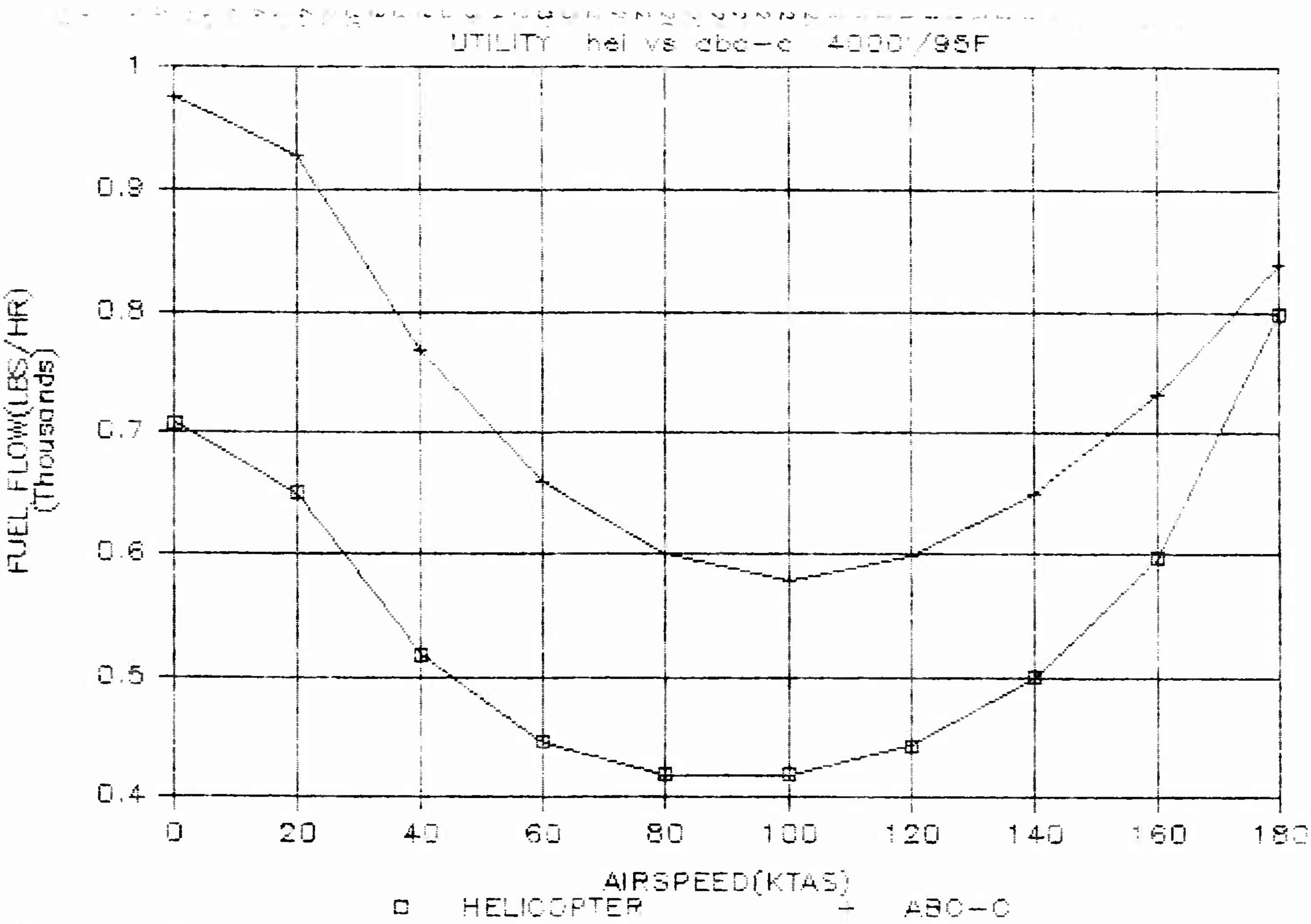

Figure N-VII-27. Utility fuel flow: helicopter and ABC-compound, 4,000'/95°F.

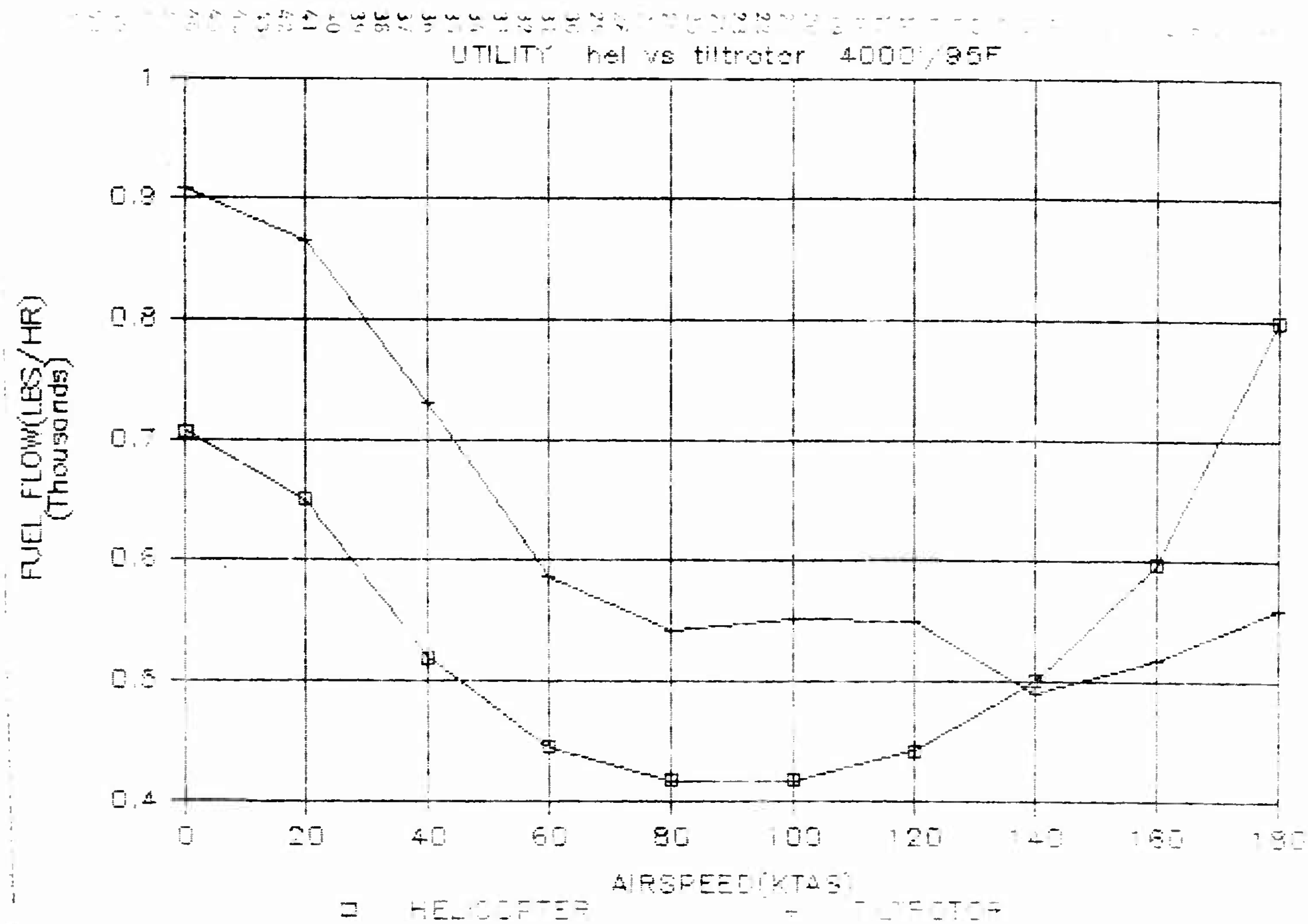

Figure N-VII-28. Utility fuel flow: helicopter and tilt rotor, 4,000'/95°F.

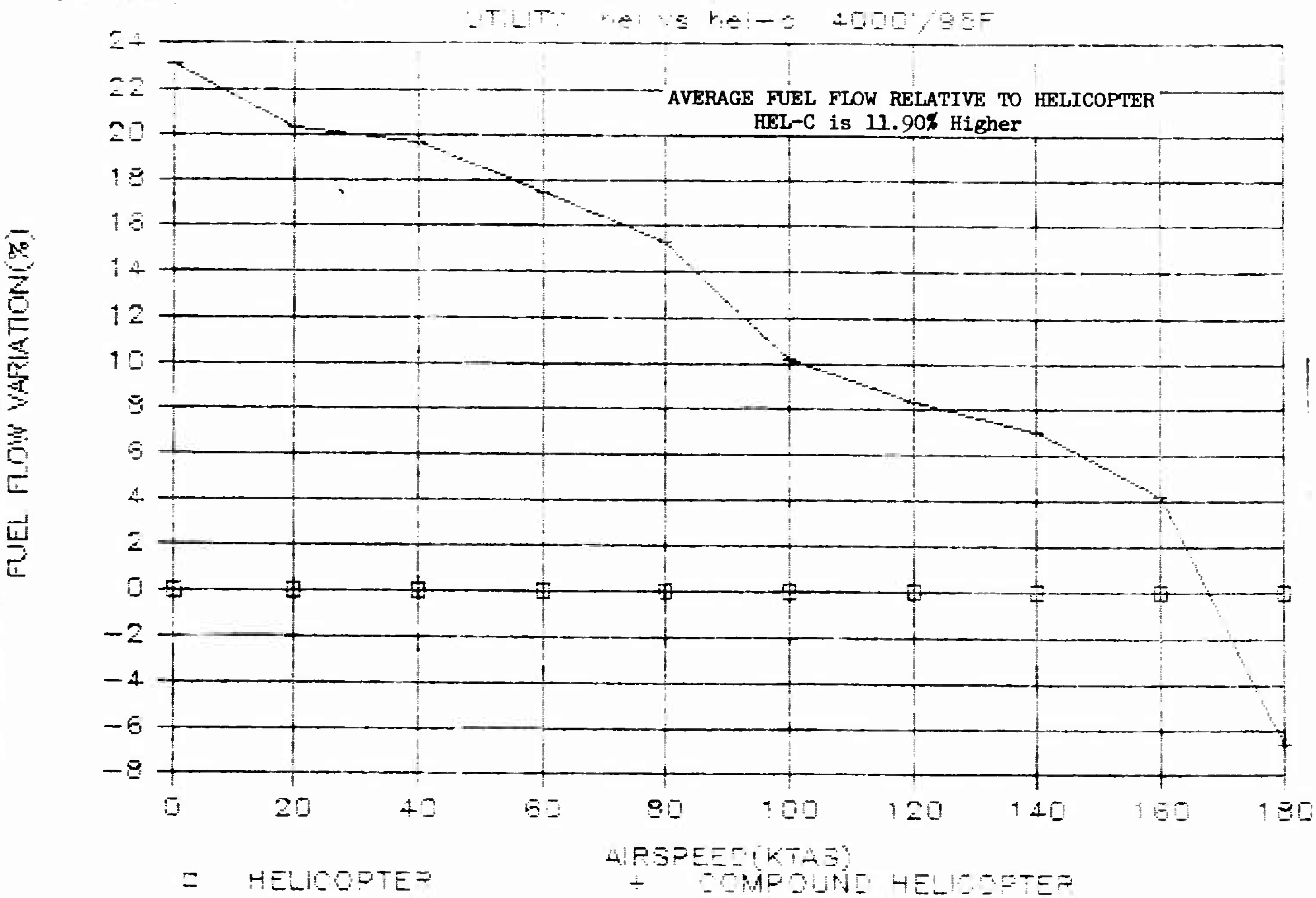

Figure N-VII-29. Utility fuel flow variation: helicopter and helicopter-compound, 4,000'/95°F.

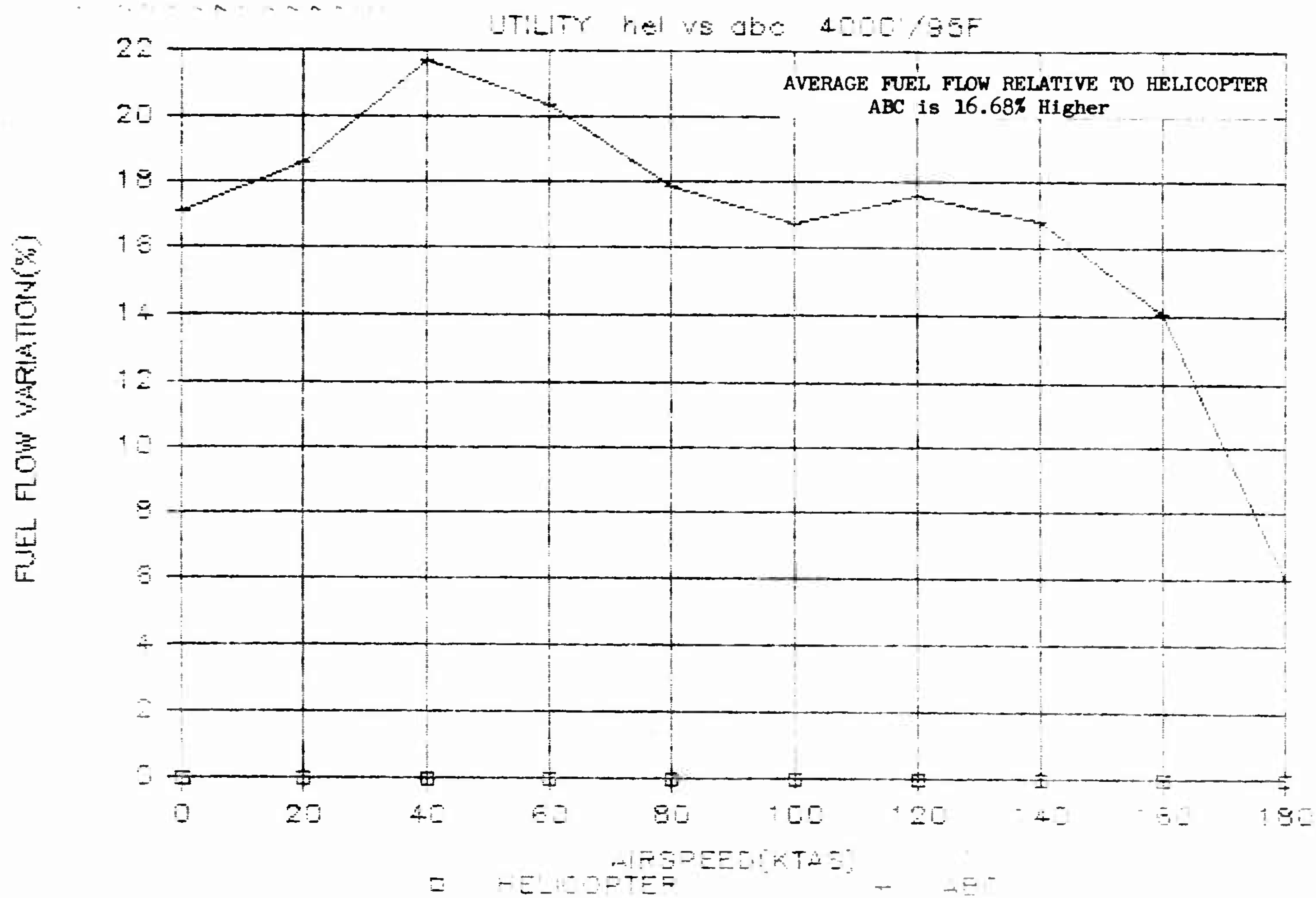

Figure N-VII-30. Utility fuel flow variation: helicopter and ABC, 4,000'/95°F.

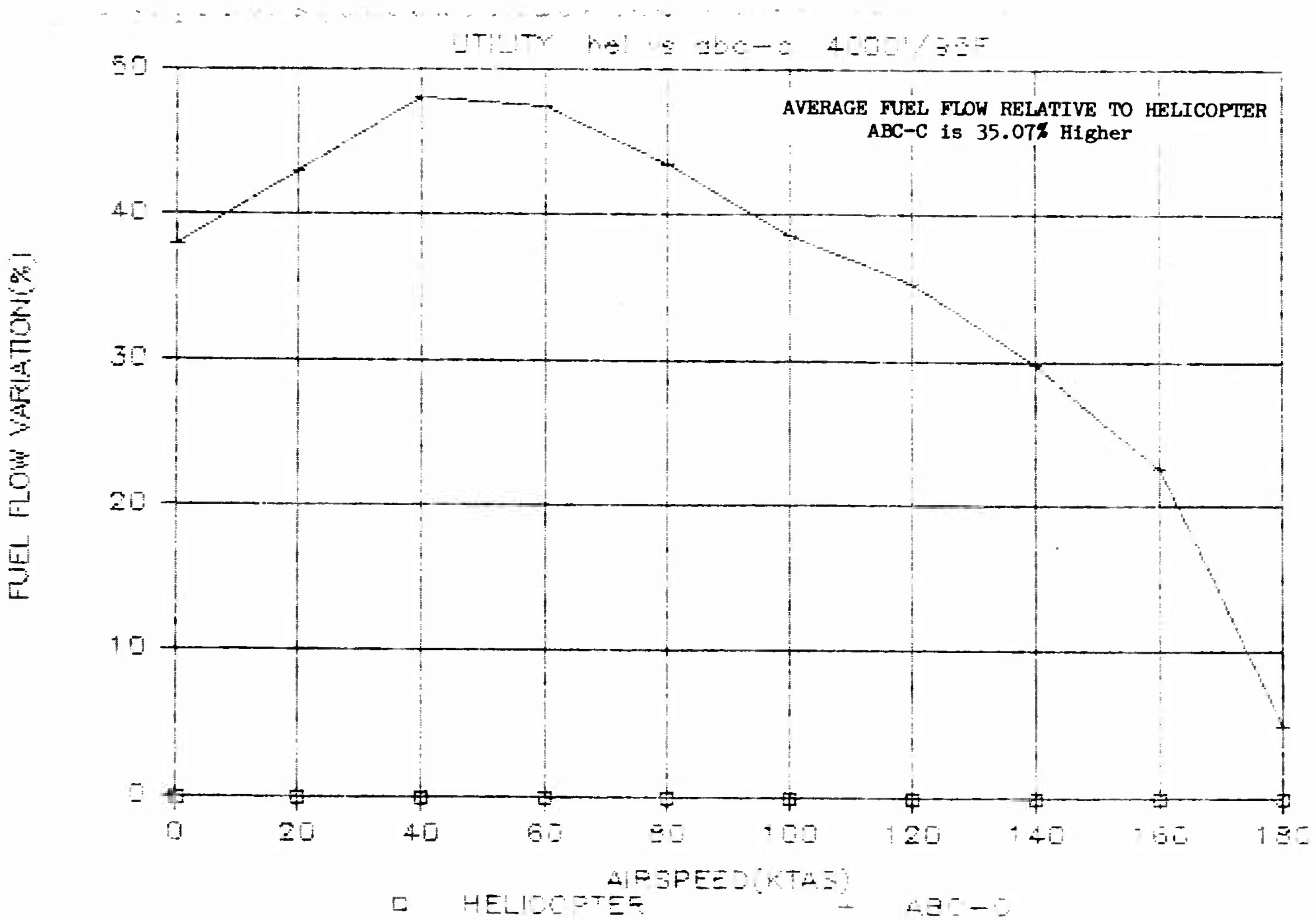

Figure N-VII-31. Utility fuel flow variation: helicopter and ABC-compound, 4,000'/95°F.

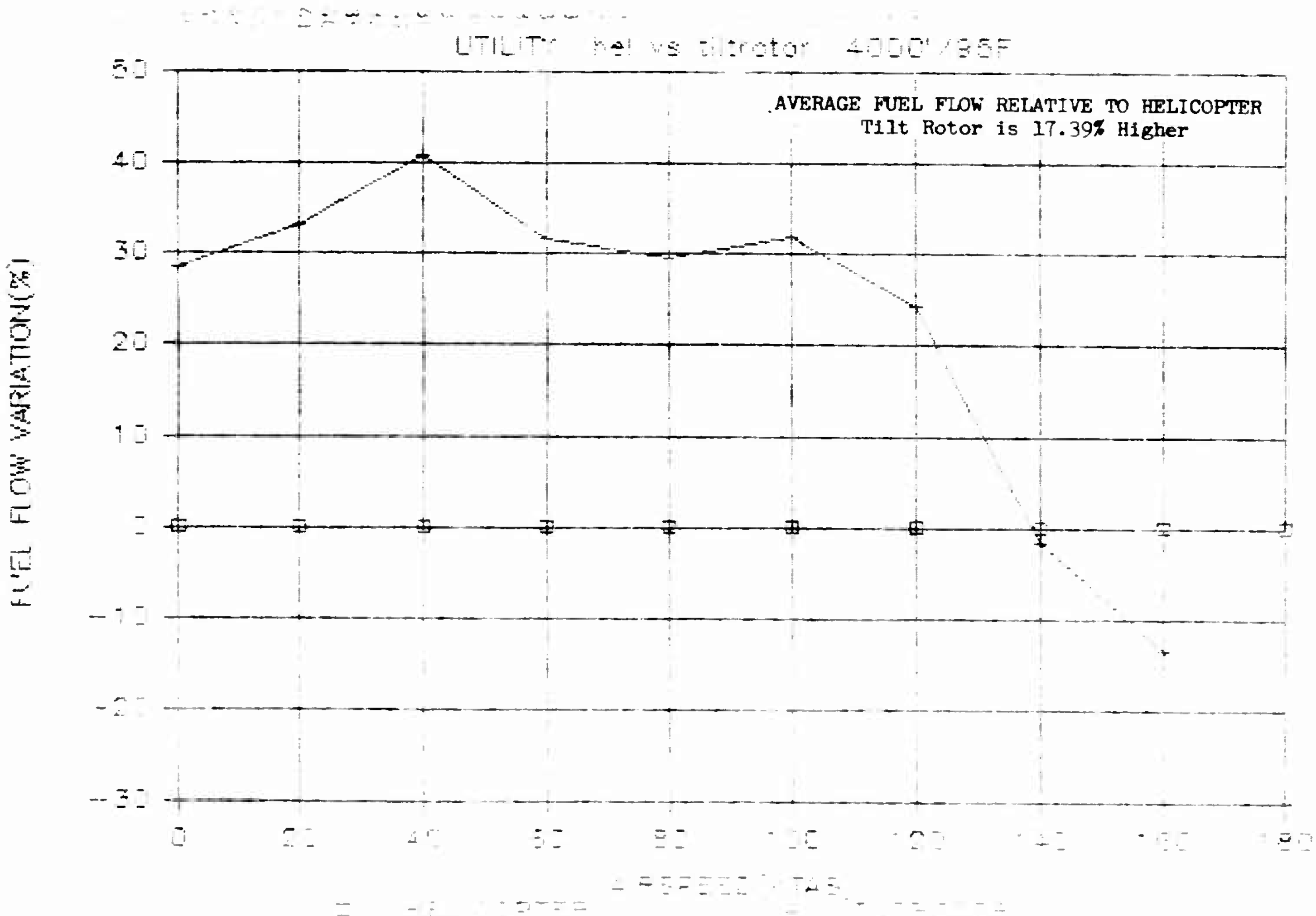

Figure N-VII-32. Utility fuel flow variation: helicopter and tilt rotor, 4,000'/95°F.

Table N-VII-4. LHX-SCAT cruise efficiency, 4,000 ft/95°F.

AVERAGE PERCENT DIFFERENCE IN FUEL FLOW (0-180 KT)

Configuration	Percent Difference
Helicopter	0
Compound Helicopter	11.90
ABC	16.68
Compound ABC	35.07
TR	17.39

c. SCAT: 2,000 ft/70°F.

(1) Figures N-VII-23 through N-VII-36 present the power required comparisons of the different designs. Corresponding variations in power are presented in figures N-VII-37 through N-VII-40. The range of variations in power is presented in table N-VII-5.

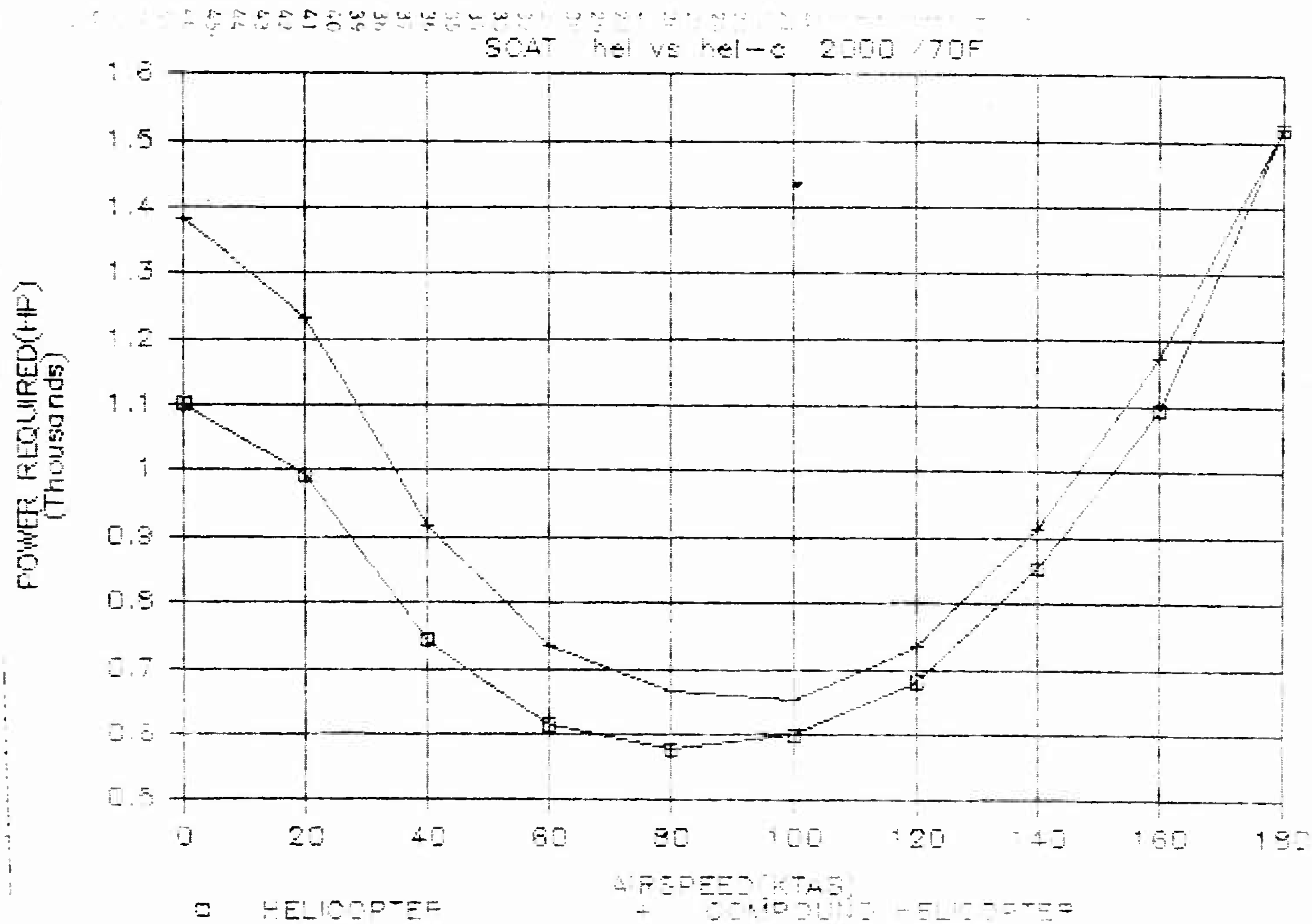

Figure N-VII-33. SCAT power required: helicopter and helicopter-compound, 2,000'/70°F.

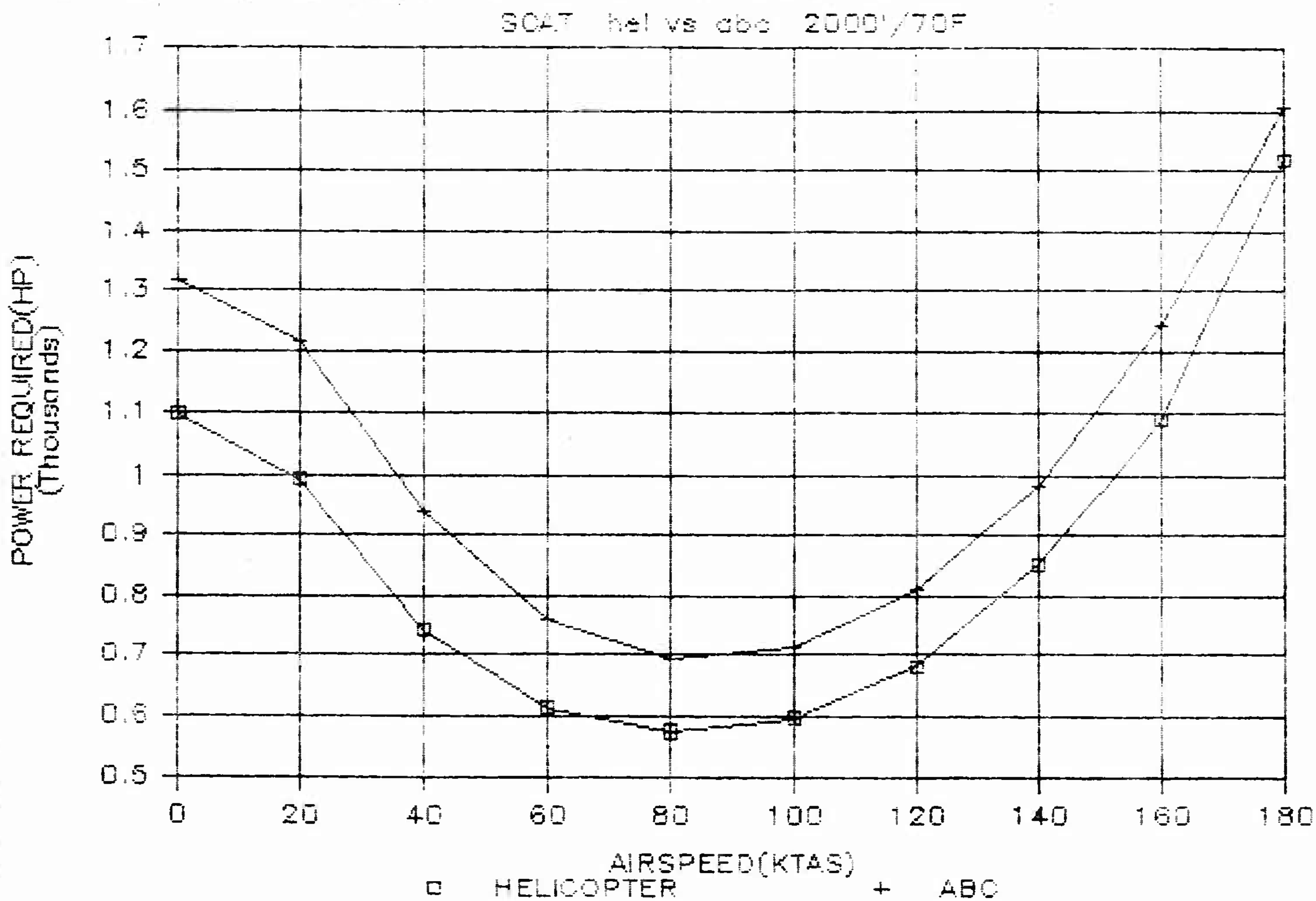

Figure N-VII-34. SCAT power required: helicopter and ABC, 2,000'/70°F.

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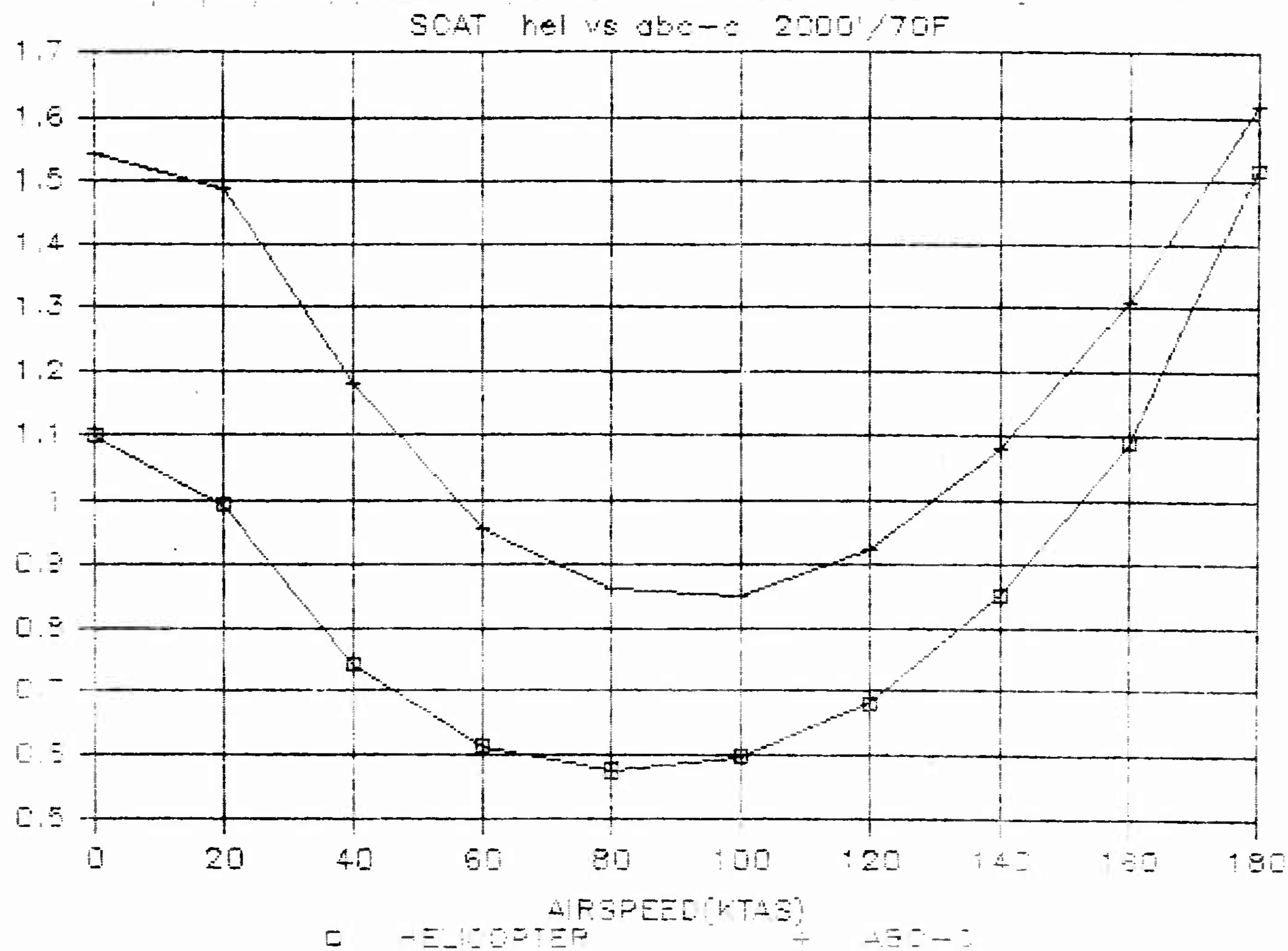

Figure N-VII-35. SCAT power required: helicopter and ABC-compound, 2,000'/70°F.

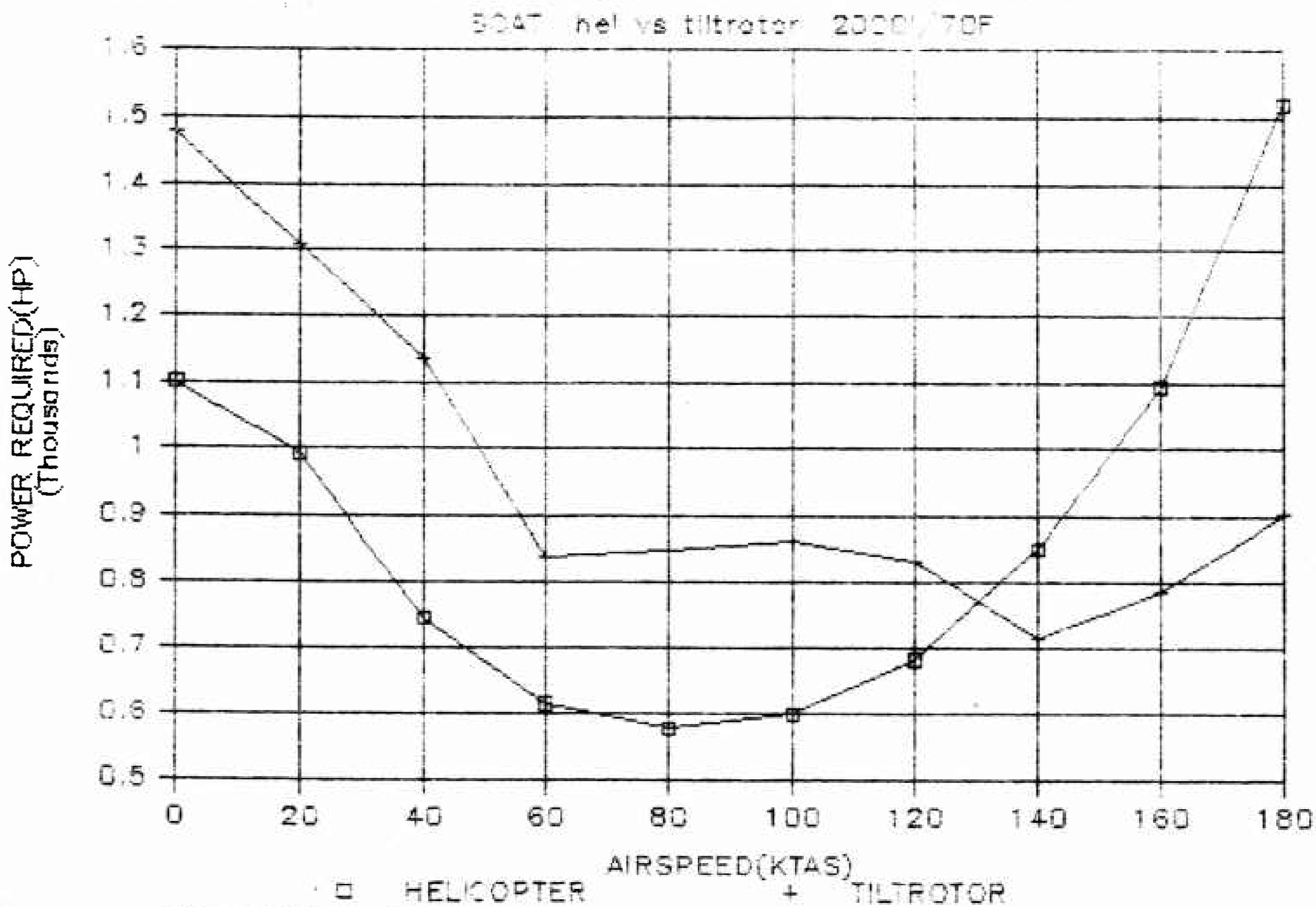

Figure N-VII-36. SCAT power required: helicopter and tilt rotor, 2,000'/70°F.

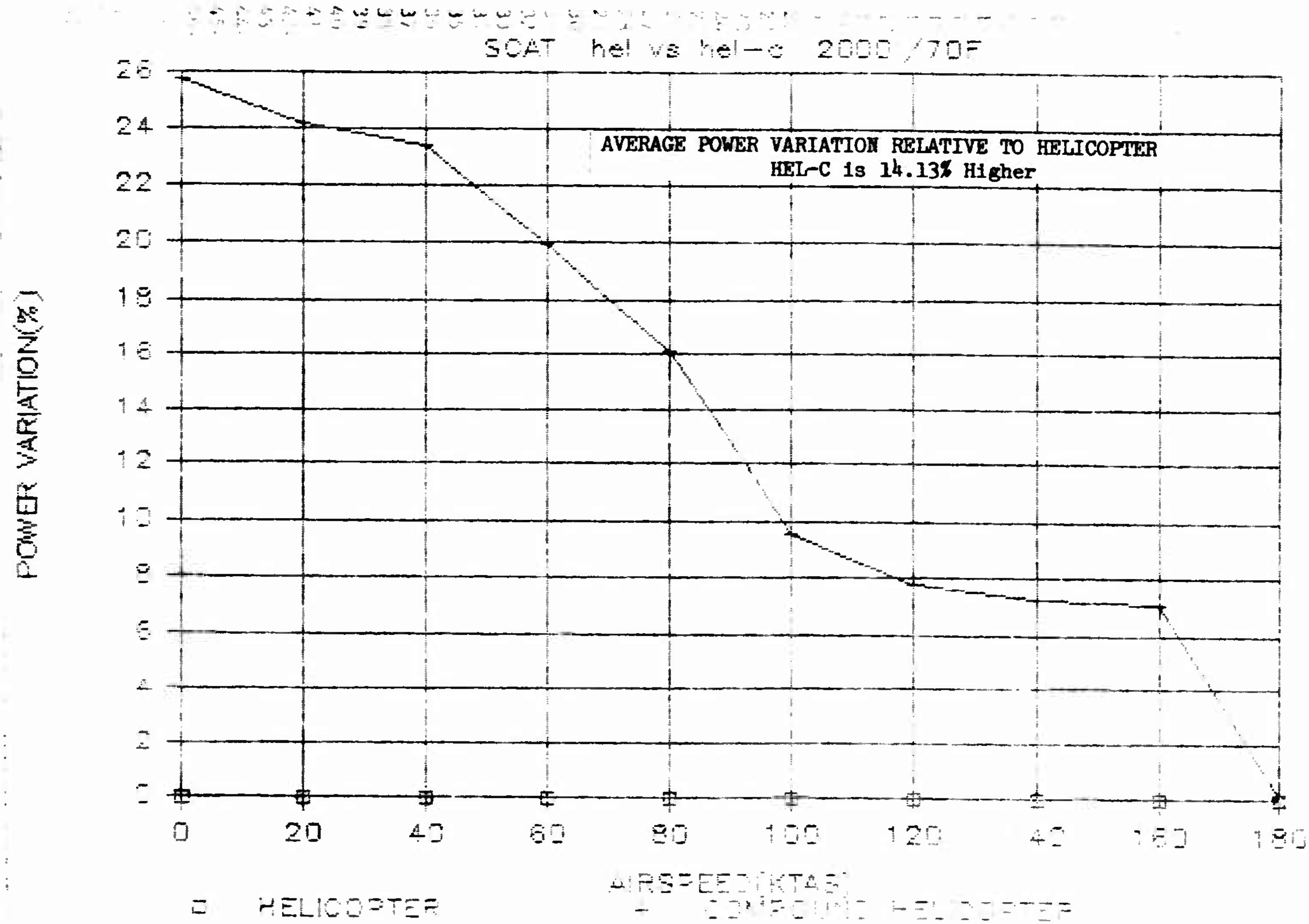

Figure N-VII-37. SCAT power variation: helicopter and helicopter-compound, 2,000'/70°F.

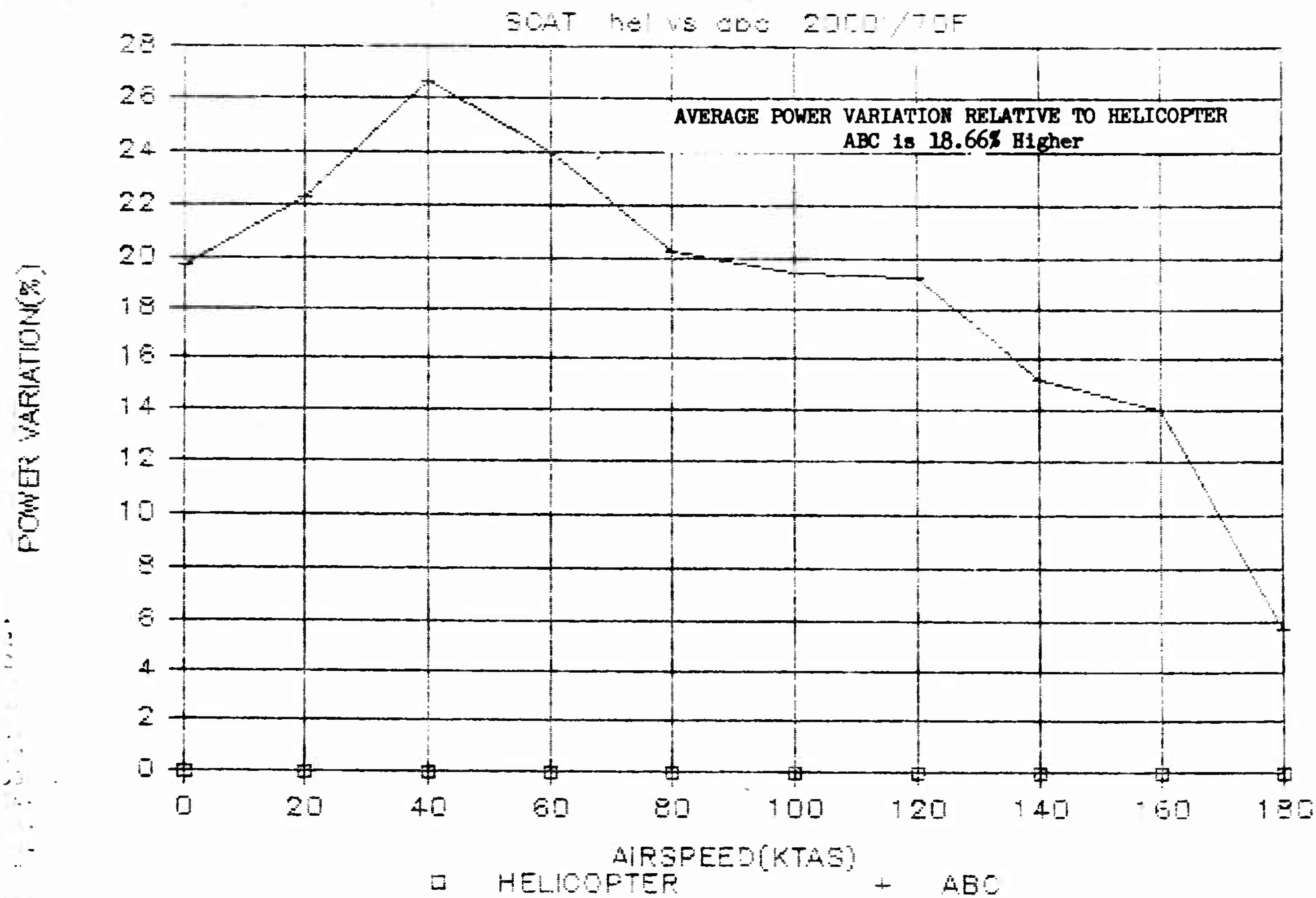

Figure N-VII-38. SCAT power variation: helicopter and ABC, 2,000'/70°F.

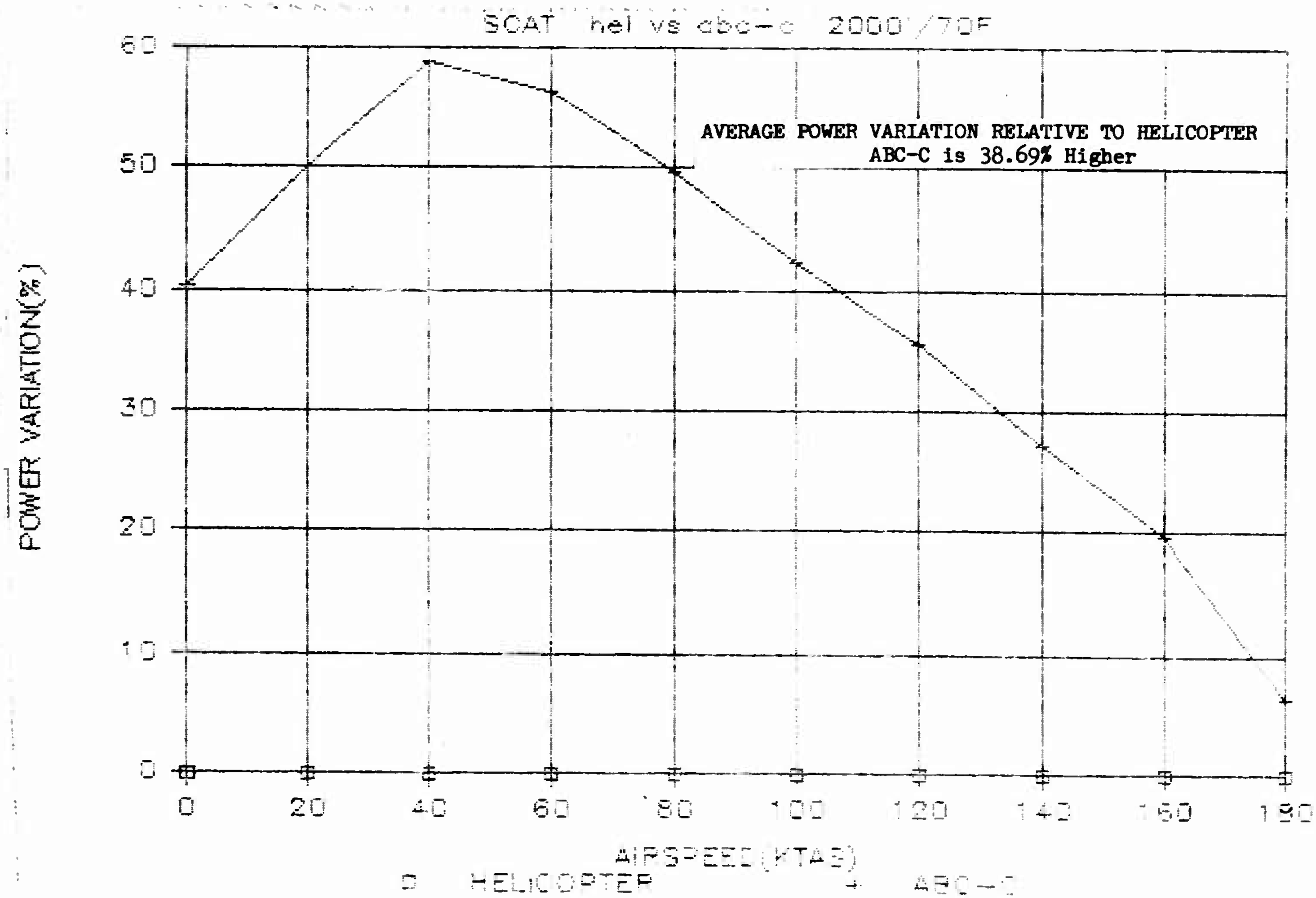

Figure N-VII-39. SCAT power variation: helicopter and ABC-compound, 2,000'/70°F.

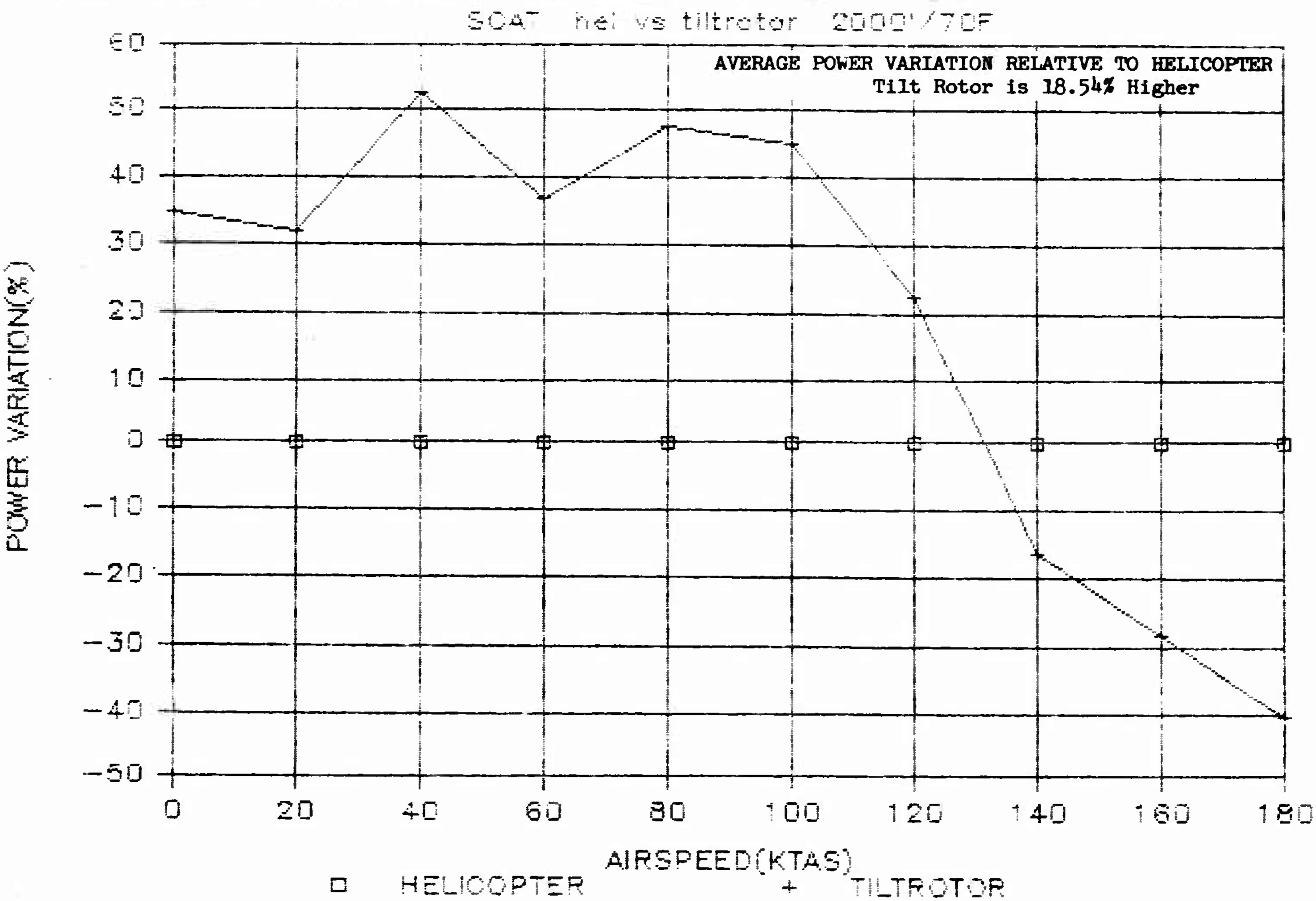

Figure N-VII-40. SCAT power variation: helicopter and tilt rotor, 2,000'/70°F.

Table N-VII-5. LHX-SCAT cruise efficiency, 2,000 ft/70°F.

AVERAGE PERCENT DIFFERENCE IN POWER REQUIRED (0-180 KT)	
Configuration	Percent Difference
Helicopter	0
Compound Helicopter	14.12
ABC	18.66
Compound ABC	38.69
TR	18.54

(2) Fuel flow comparisons are presented in figures N-VII-41 through N-VII-44. Fuel flow variations are presented in figures N-VII-45 through N-VII-48. A summary of the differences is presented in table N-VII-6.

Table N-VII-6. LHX-SCAT cruise efficiency, 2,000 ft/70°F.

AVERAGE PERCENT DIFFERENCE IN FUEL FLOW (0-180 KT)	
Configuration	Percent Difference
Helicopter	0
Compound Helicopter	15.43
ABC	16.82
Compound ABC	35.49
TR	20.14

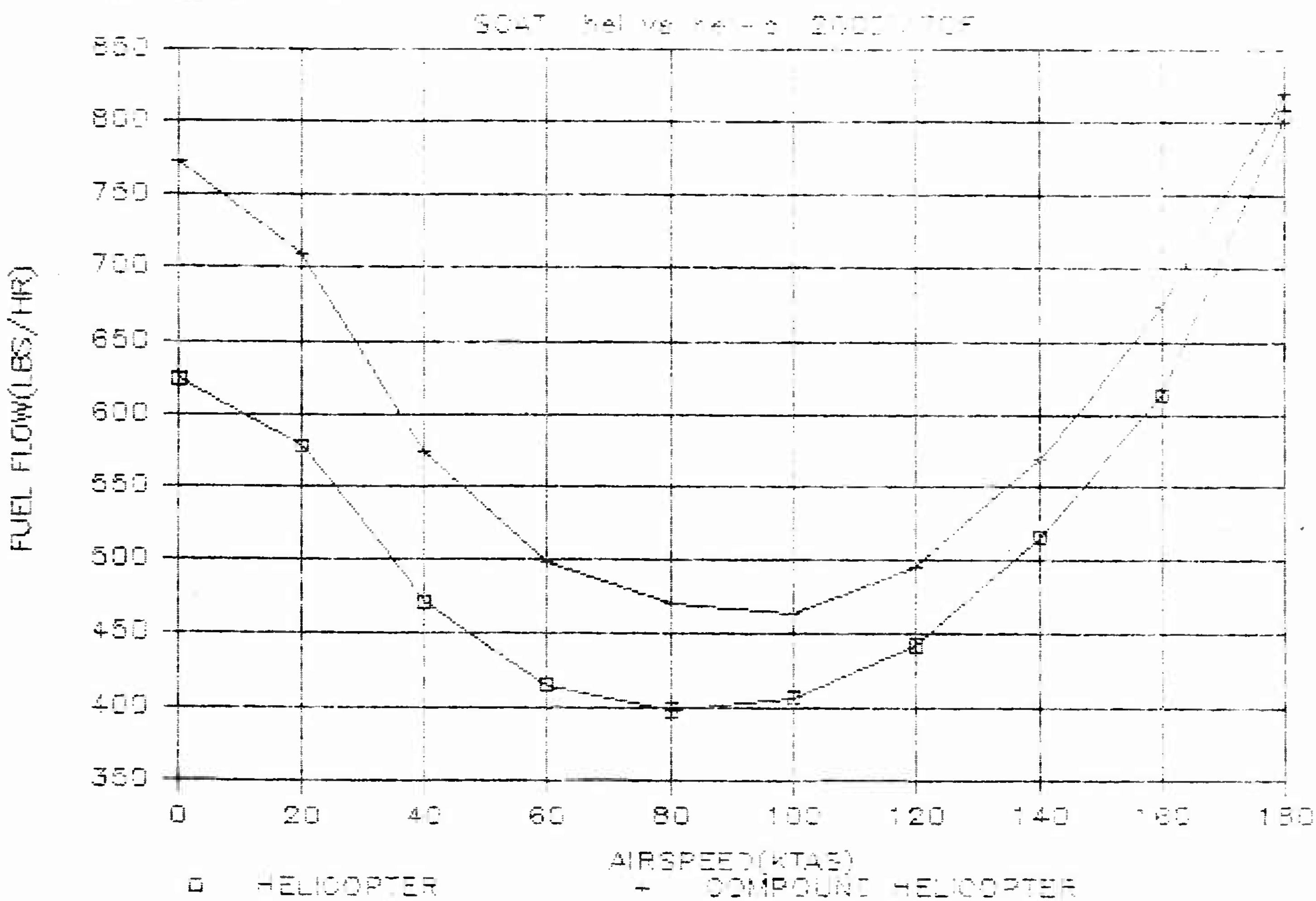

Figure N-VII-41. **SCAT fuel flow: helicopter and helicopter-compound, 2,000'/70°F.**

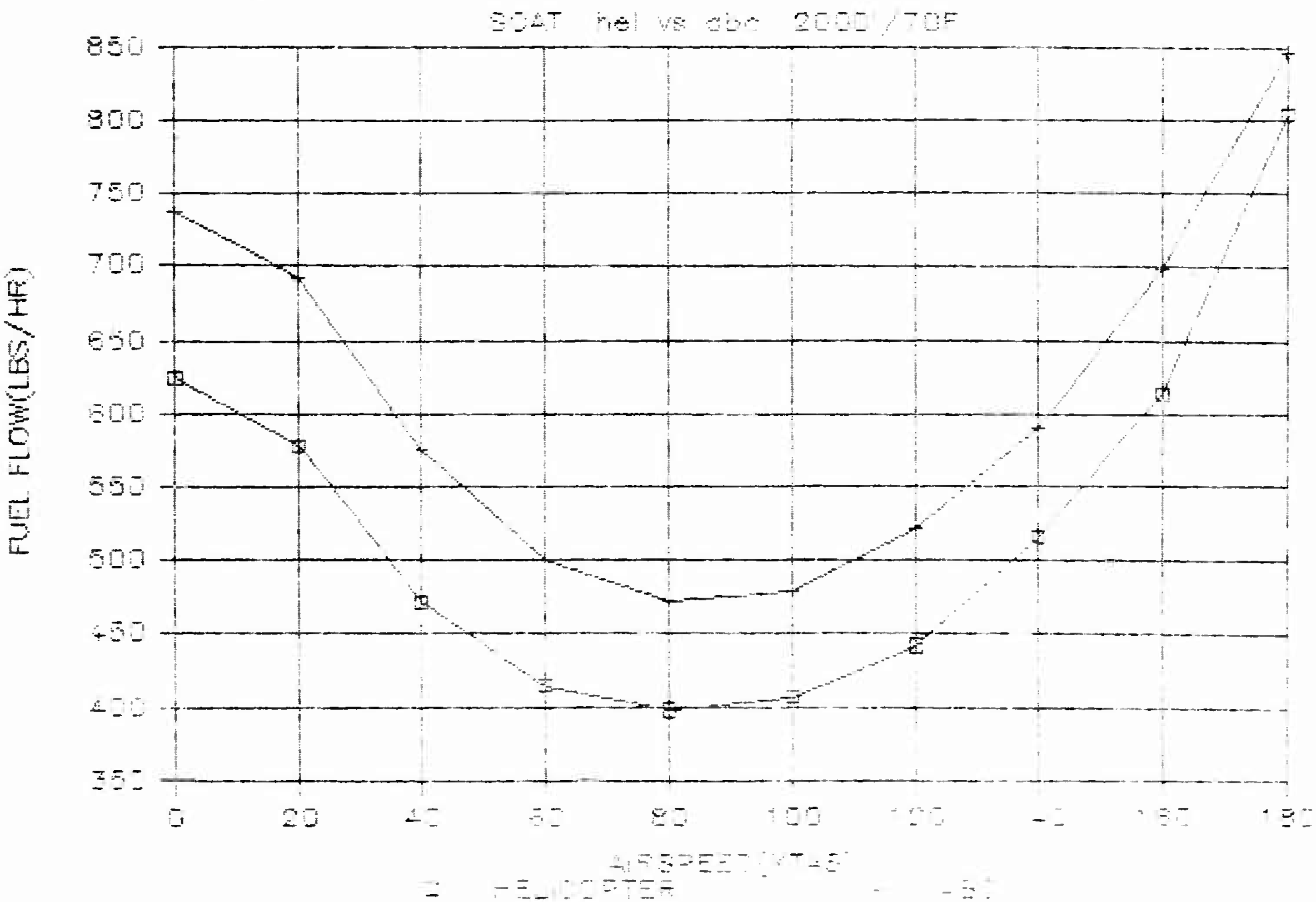

Figure N-VII-42. SCAT fuel flow: helicopter and ABC, 2,000'/70°F.

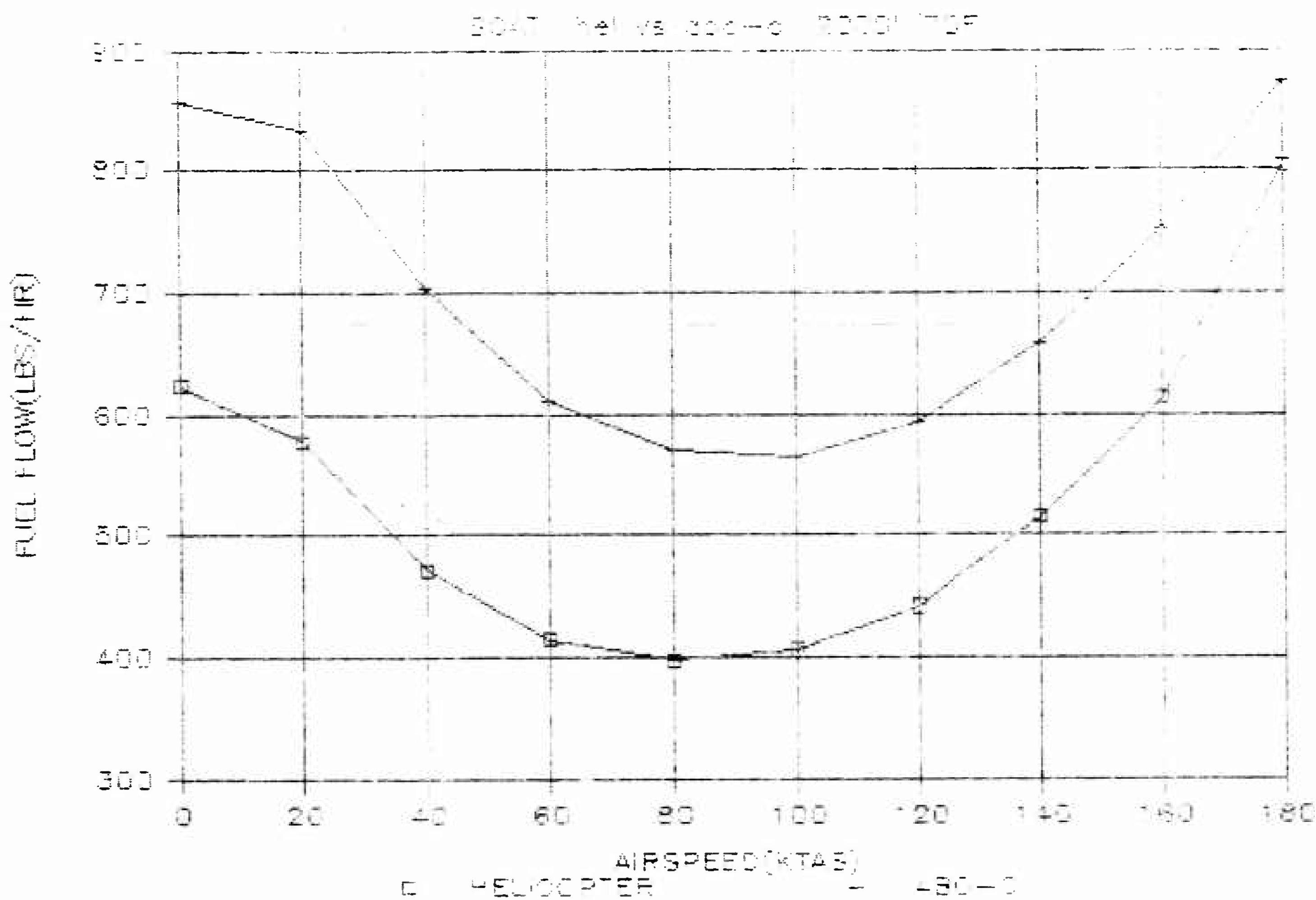

Figure N-VII-43. SCAT fuel flow: helicopter and ABC-compound, 2,000'/70°F.

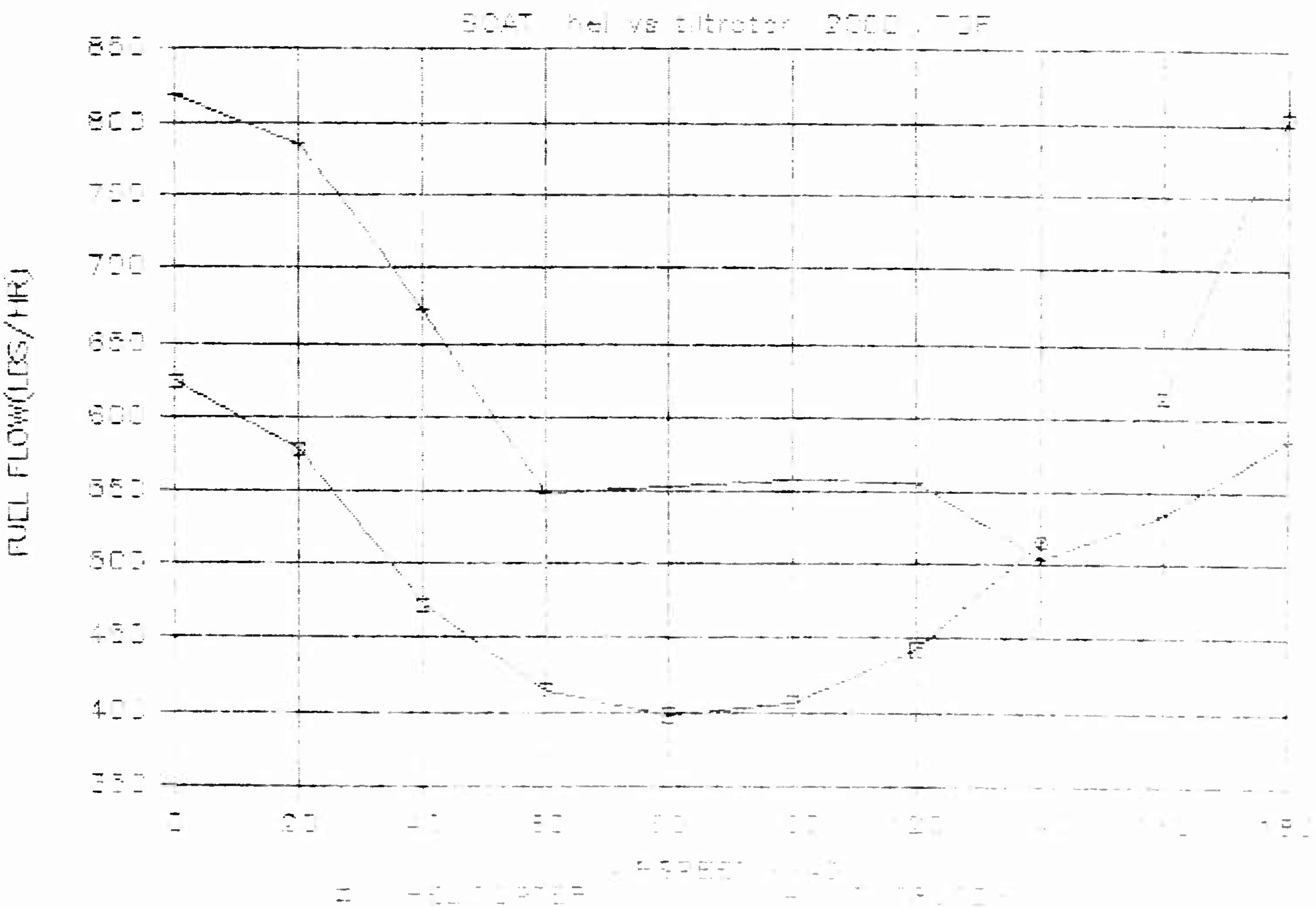

Figure N-VII-44. SCAT fuel flow: helicopter and tilt rotor, 2,000'/70°F.

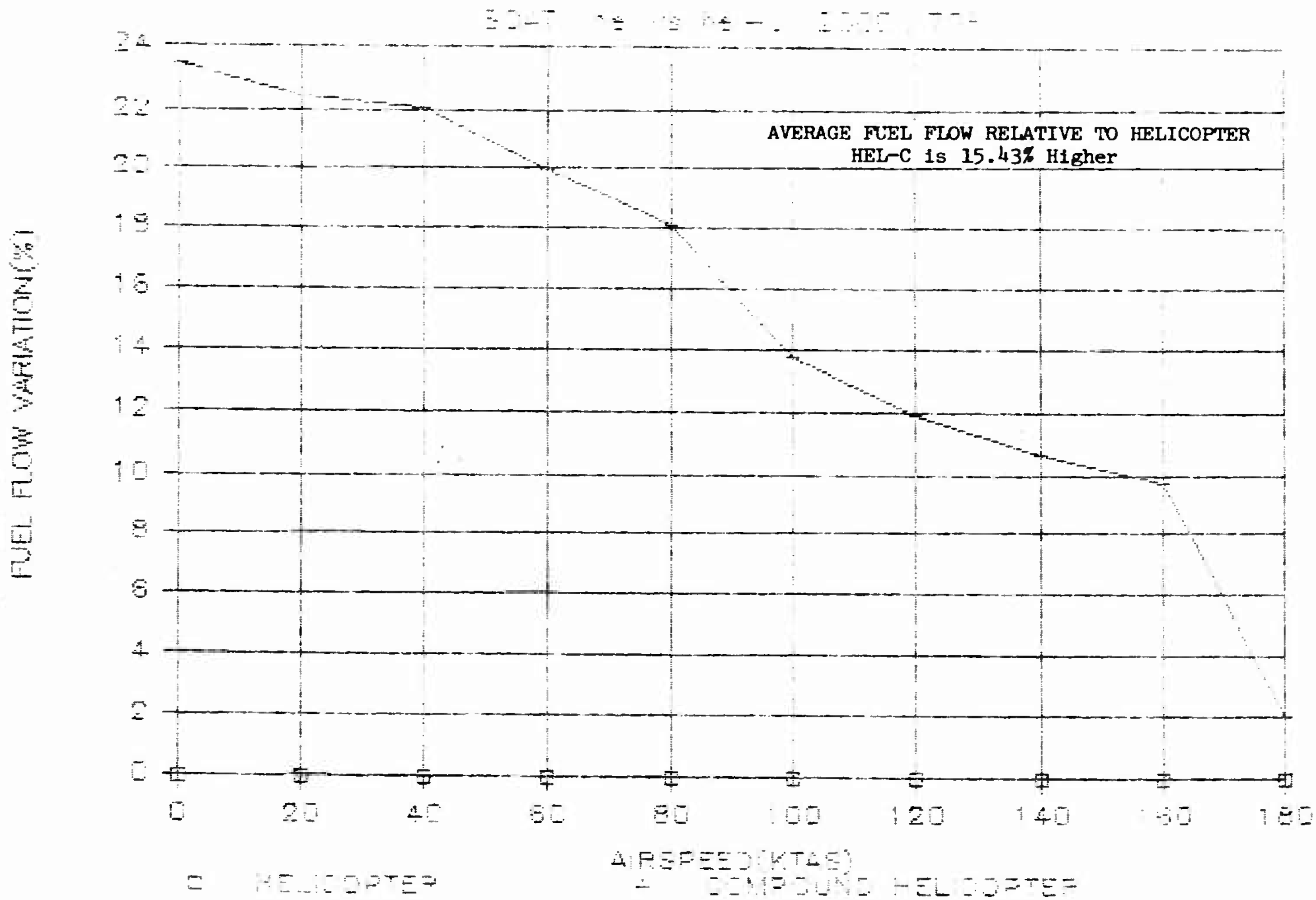

Figure N-VII-45. SCAT fuel flow variation: helicopter and helicopter-compound, 2,000'/70°F.

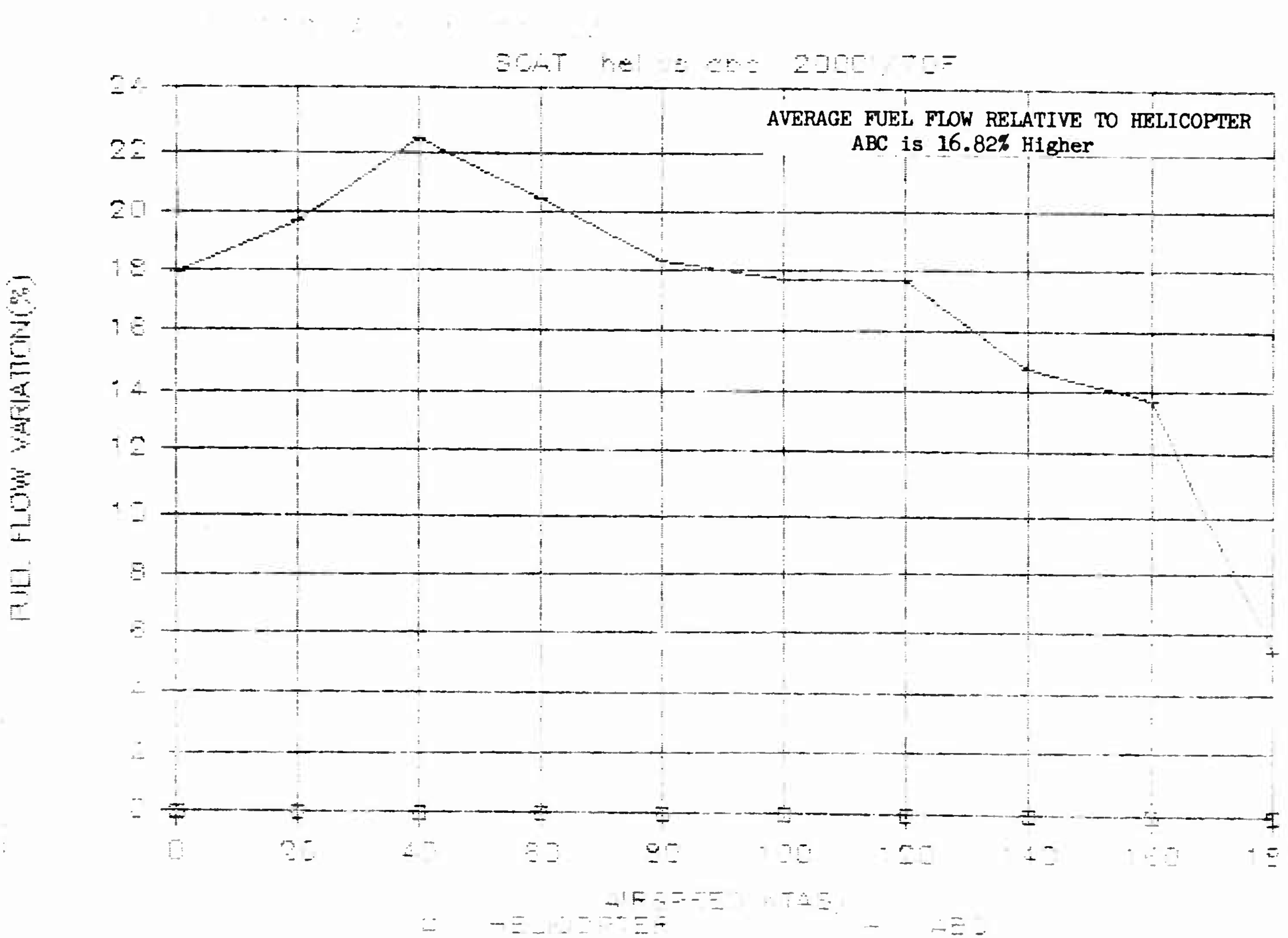

Figure N-VII-46. SCAT fuel flow variation: helicopter and ABC, 2,000'/70°F.

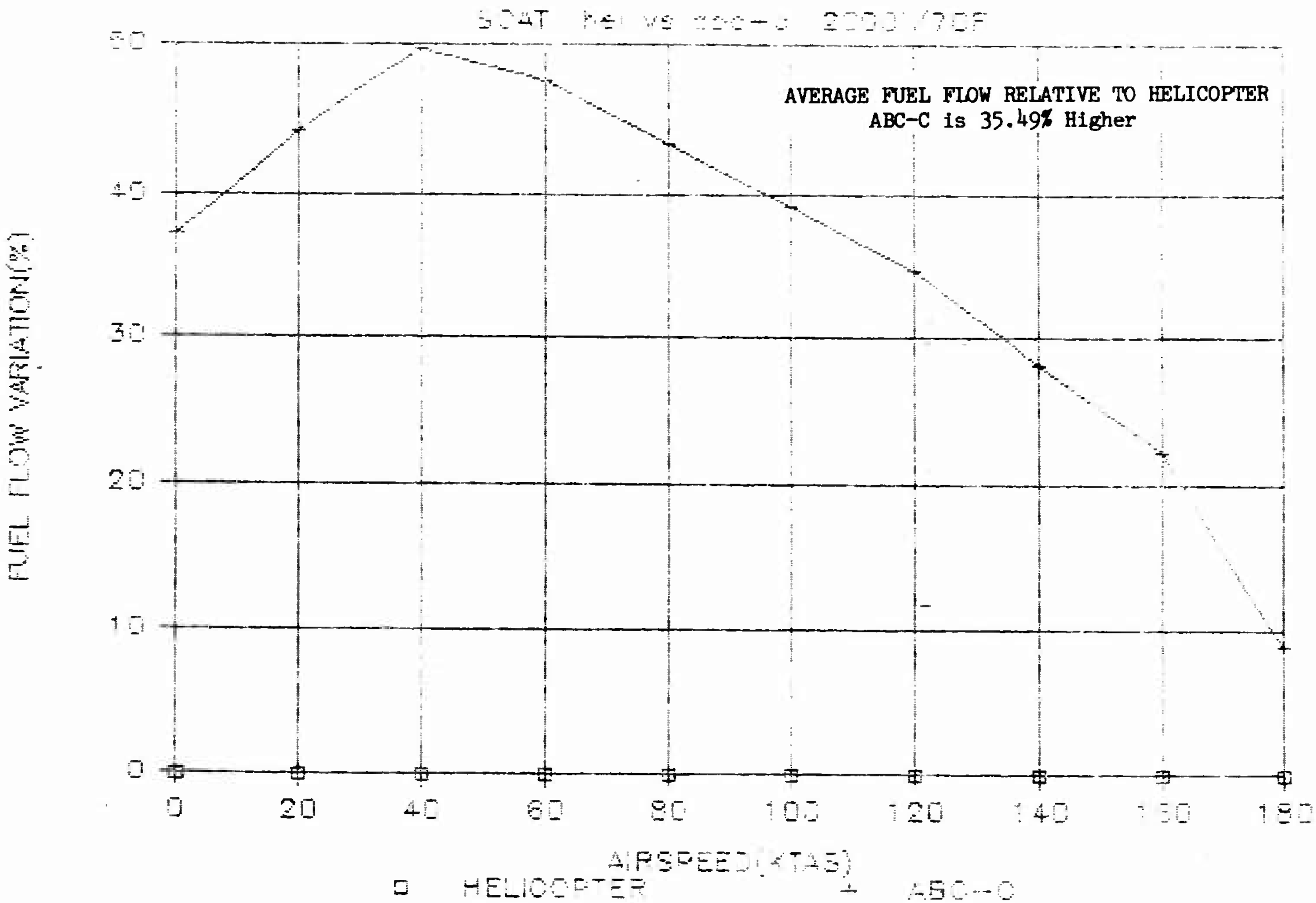

Figure N-VII-47. SCAT fuel flow variation: helicopter and ABC-compound, 2,000'/70°F.

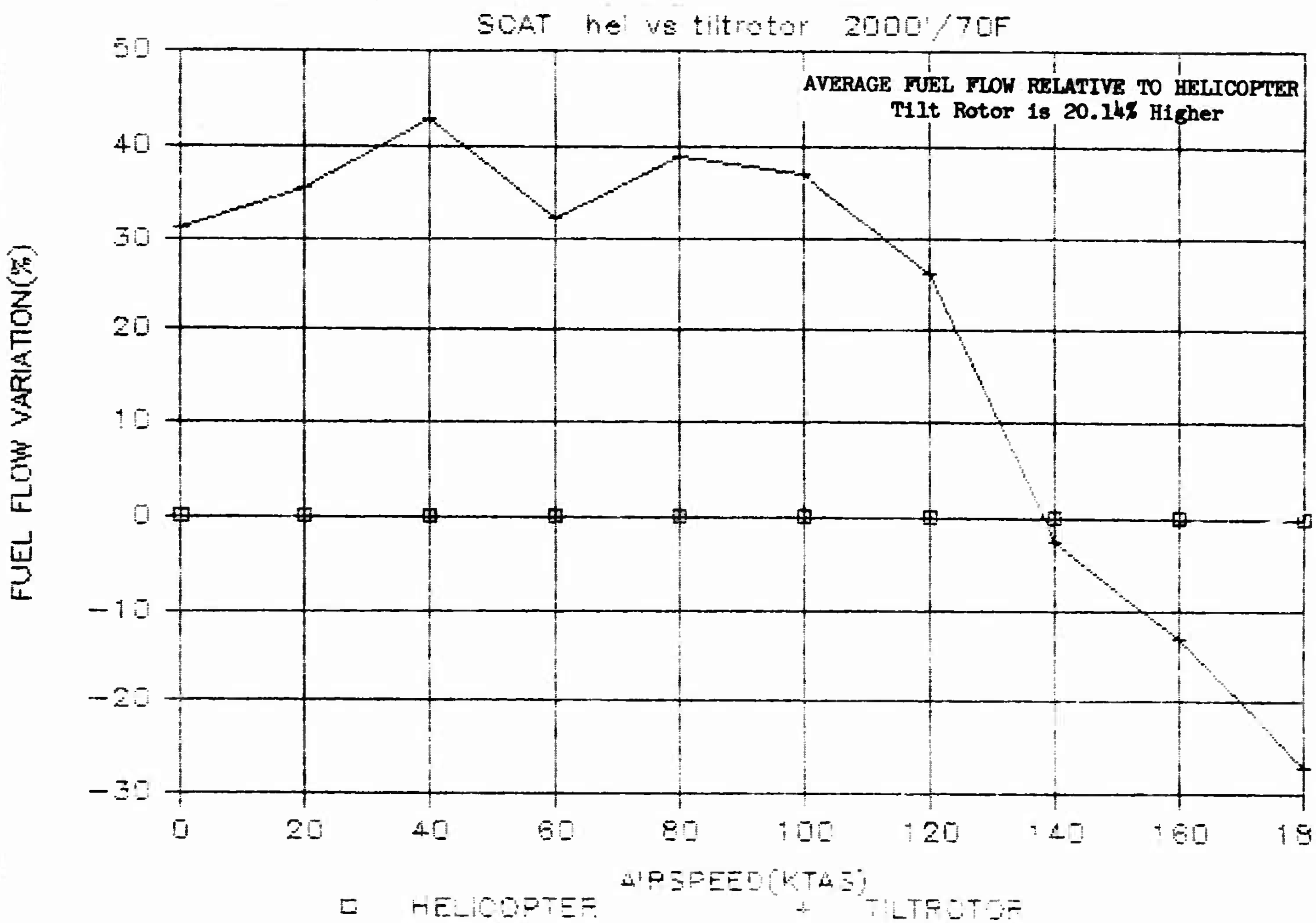

Figure N-VII-48. SCAT fuel flow variation: helicopter and tilt rotor, 2,000'/70°F.

d. Utility: 2,000 ft/70°F.

(1) Figures N-VII-49 through N-VII-52 present power required comparisons. Figures N-VII-53 through N-VII-56 present the variation in power required. The average power variations are summarized in table N-VII-7.

Table N-VII-7. LHX-Utility cruise efficiency, 2,000 ft/70°F.

AVERAGE PERCENT DIFFERENCE IN POWER REQUIRED (0-180 KT)

Configuration	Percent Difference
Helicopter	0
Compound Helicopter	10.15
ABC	16.57
Compound ABC	35.69
TR	12.65

(2) Fuel flow comparisons are presented in figures N-VII-57 through N-VII-60 with attendant fuel flow variations depicted in figures N-VII-61 through N-VII-64. A summary of the average variations is presented in table N-VII-8.

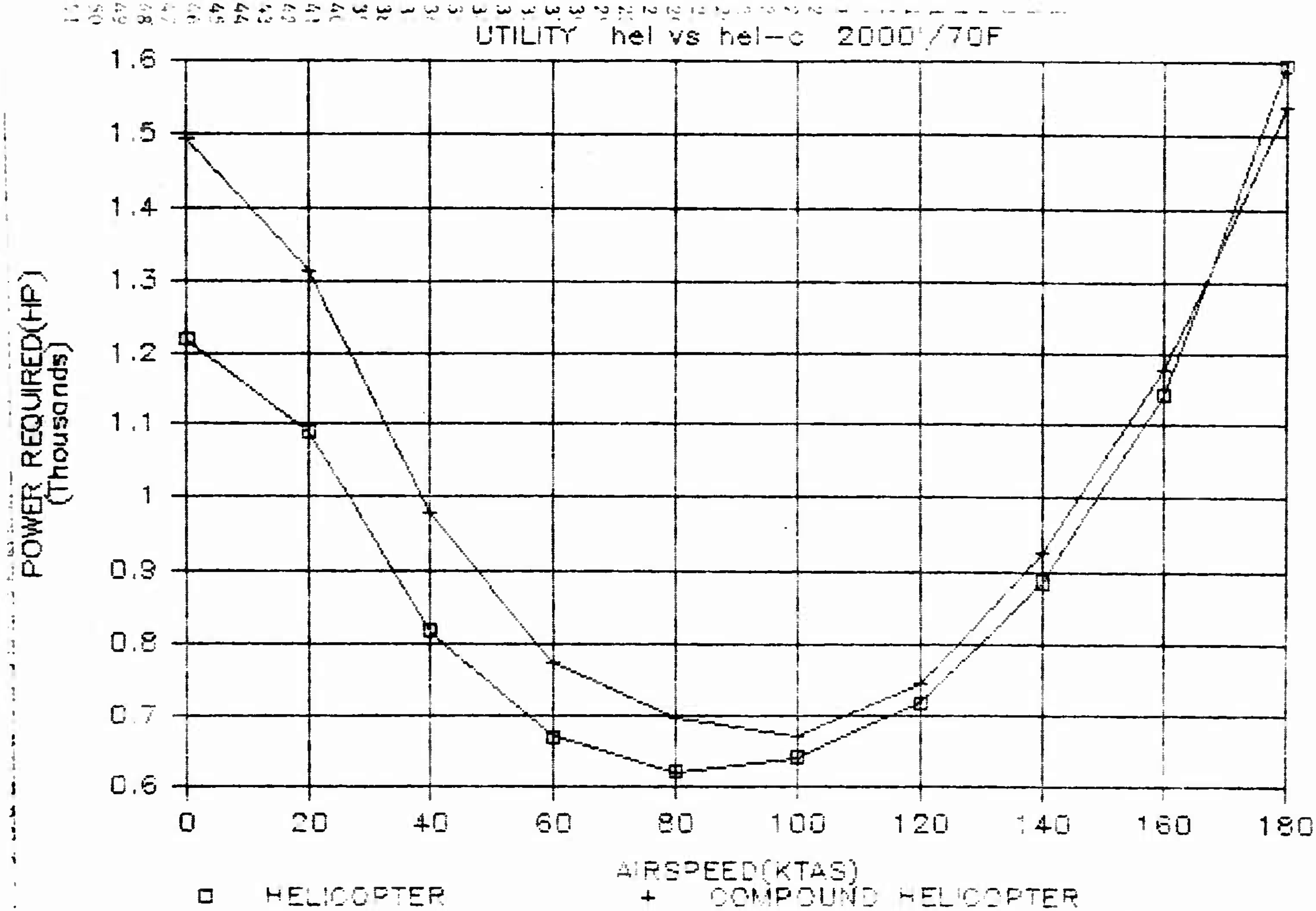

Figure N-VII-49. Utility power required: helicopter and helicopter-compound, 2,000'/70°F.

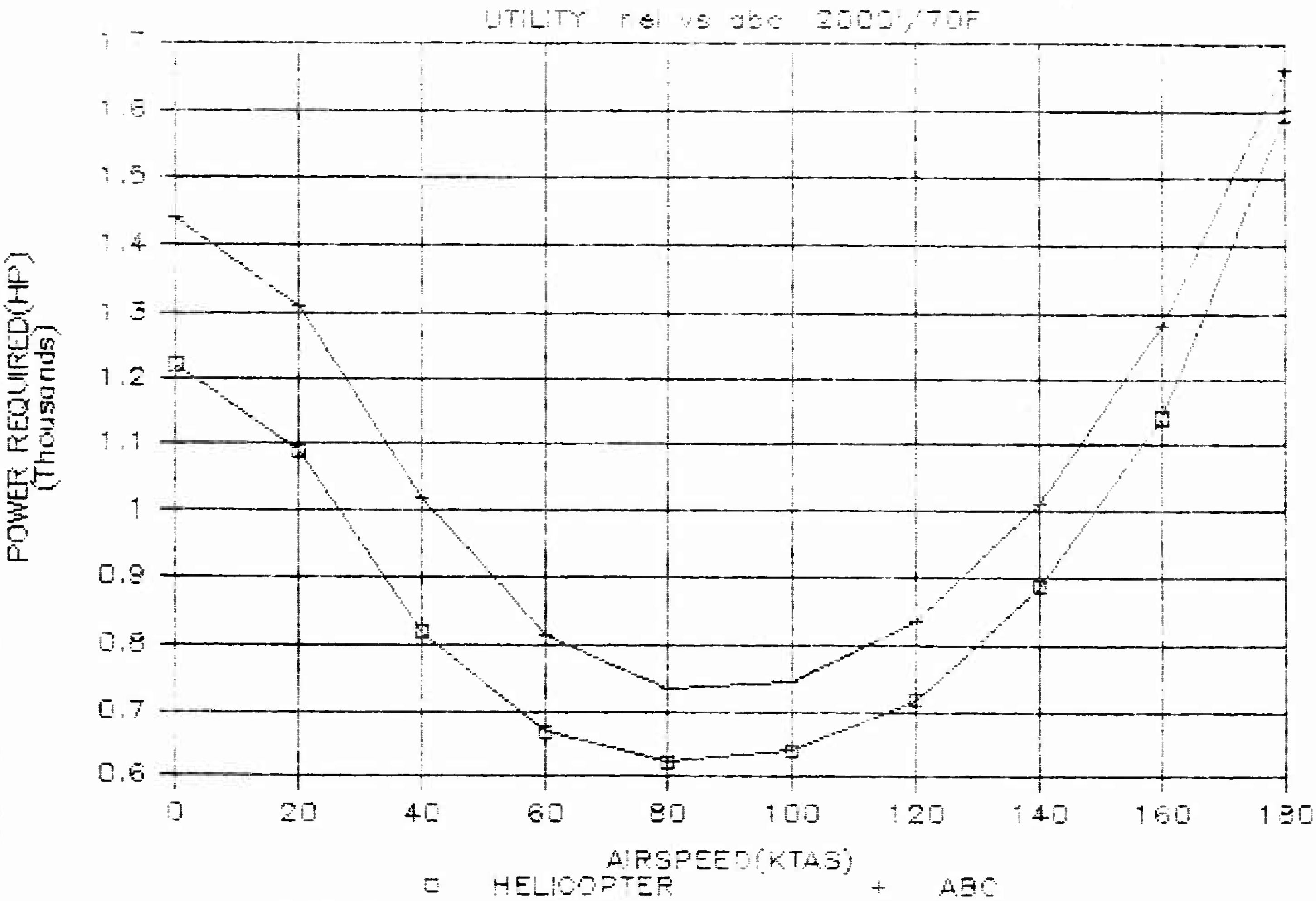

Figure N-VII-50. Utility power required: helicopter and ABC, 2,000'/70°F.

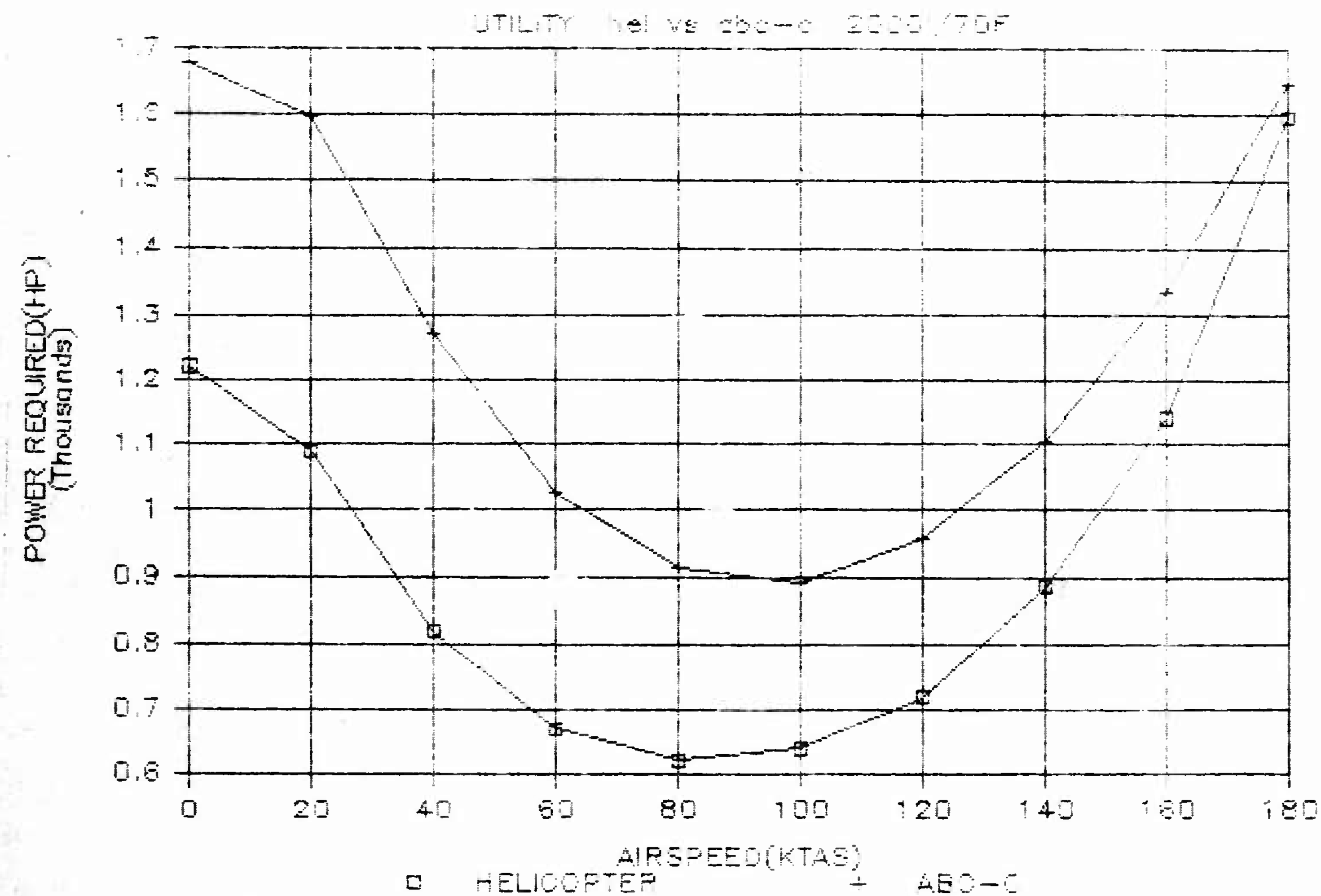

Figure N-VII-51. Utility power required: helicopter and ABC-compound, 2,000'/70°F.

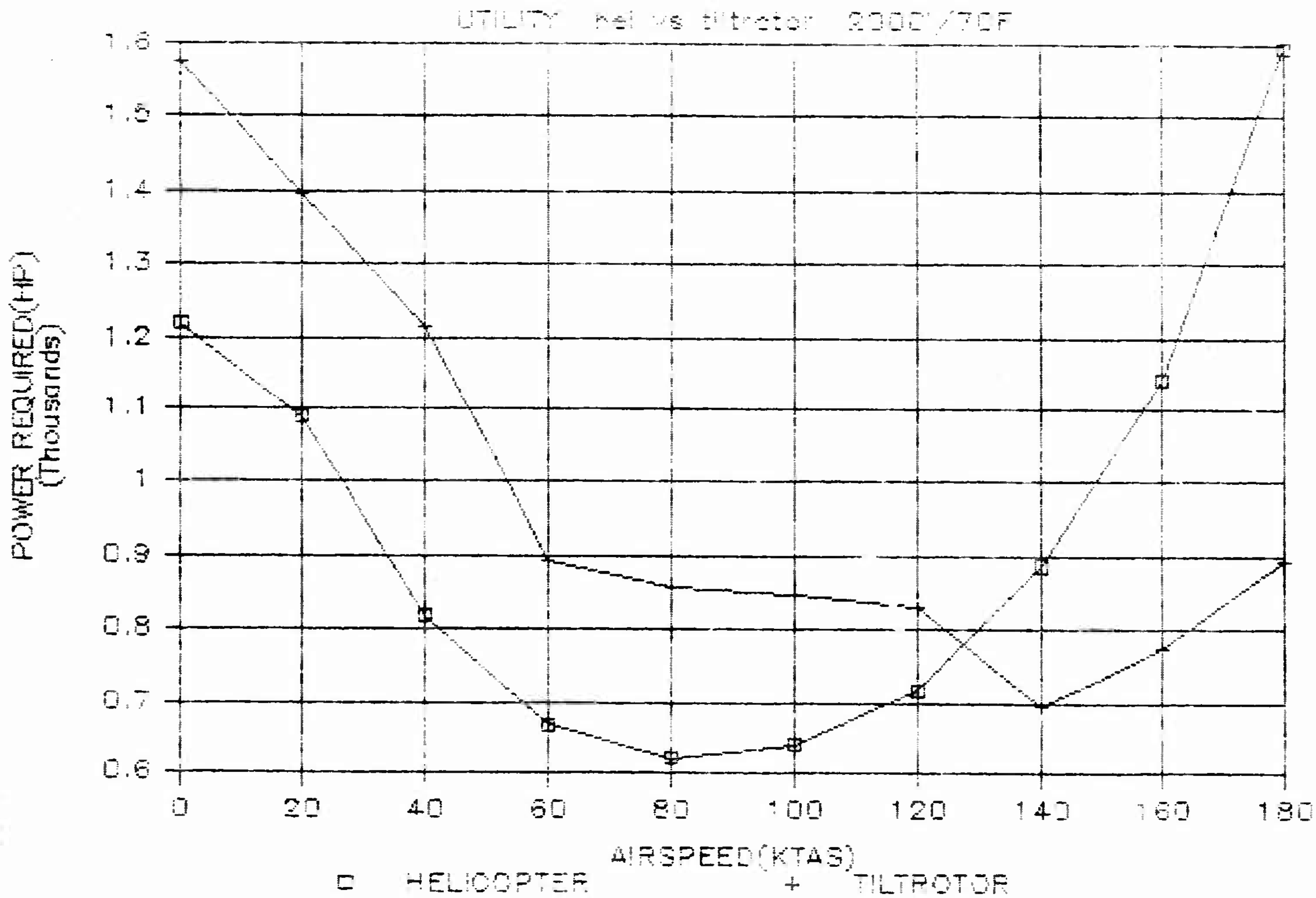

Figure N-VII-52. Utility power required: helicopter and tilt rotor, 2,000'/70°F.

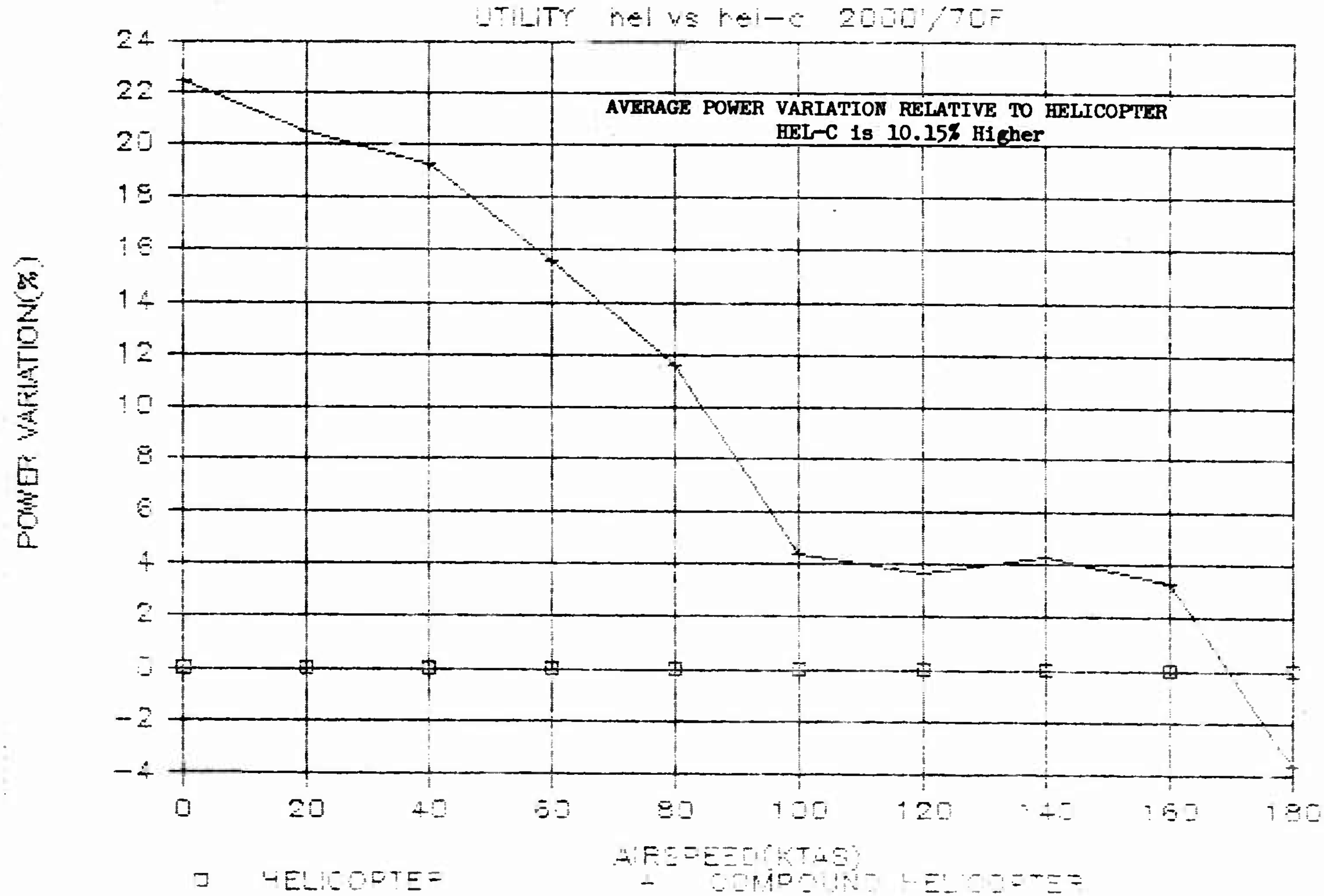

Figure N-VII-53. Utility power variation: helicopter and helicopter-compound, 2,000'/70°F.

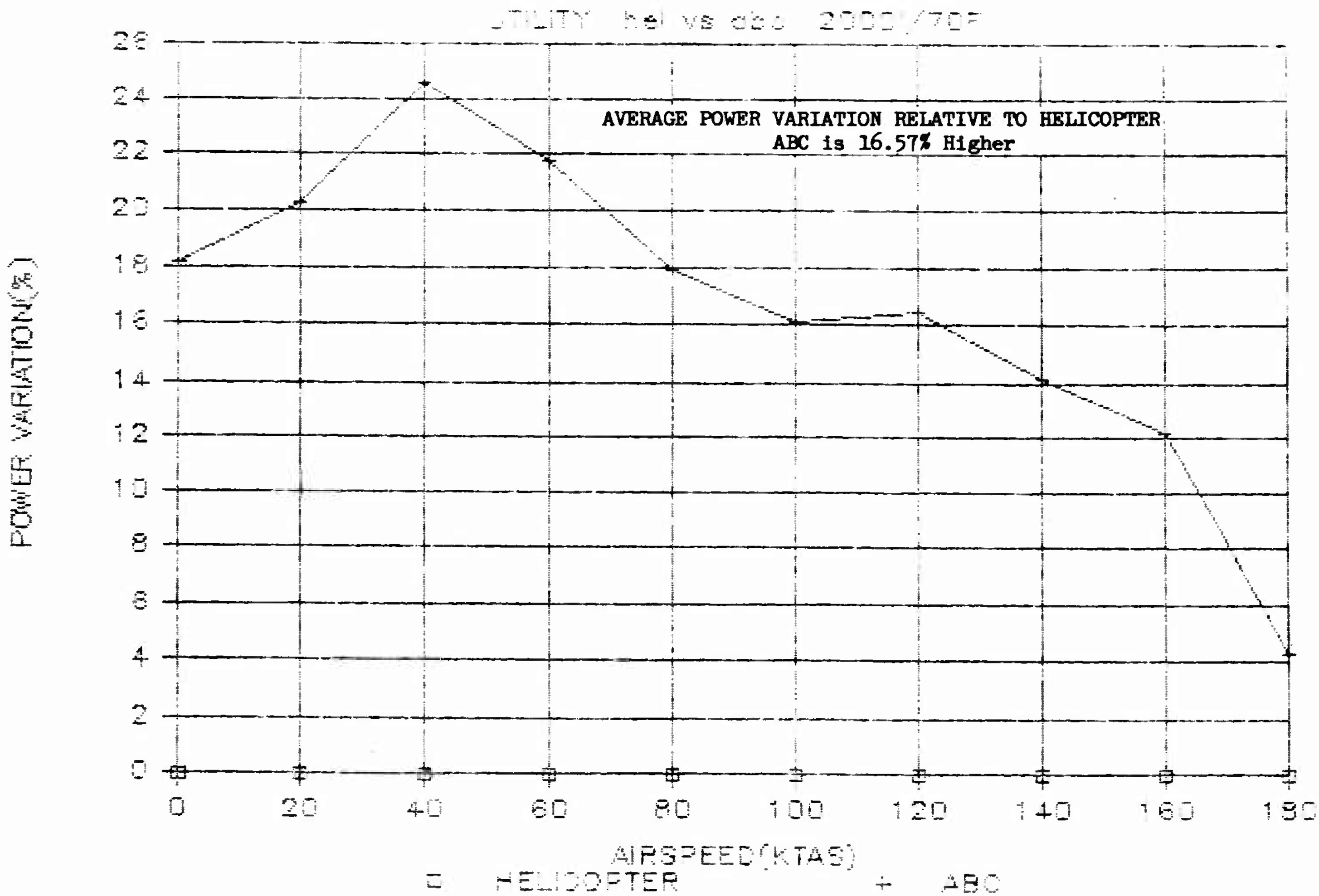

Figure N-VII-54. Utility power variation: helicopter and ABC, 2,000'/70°F.

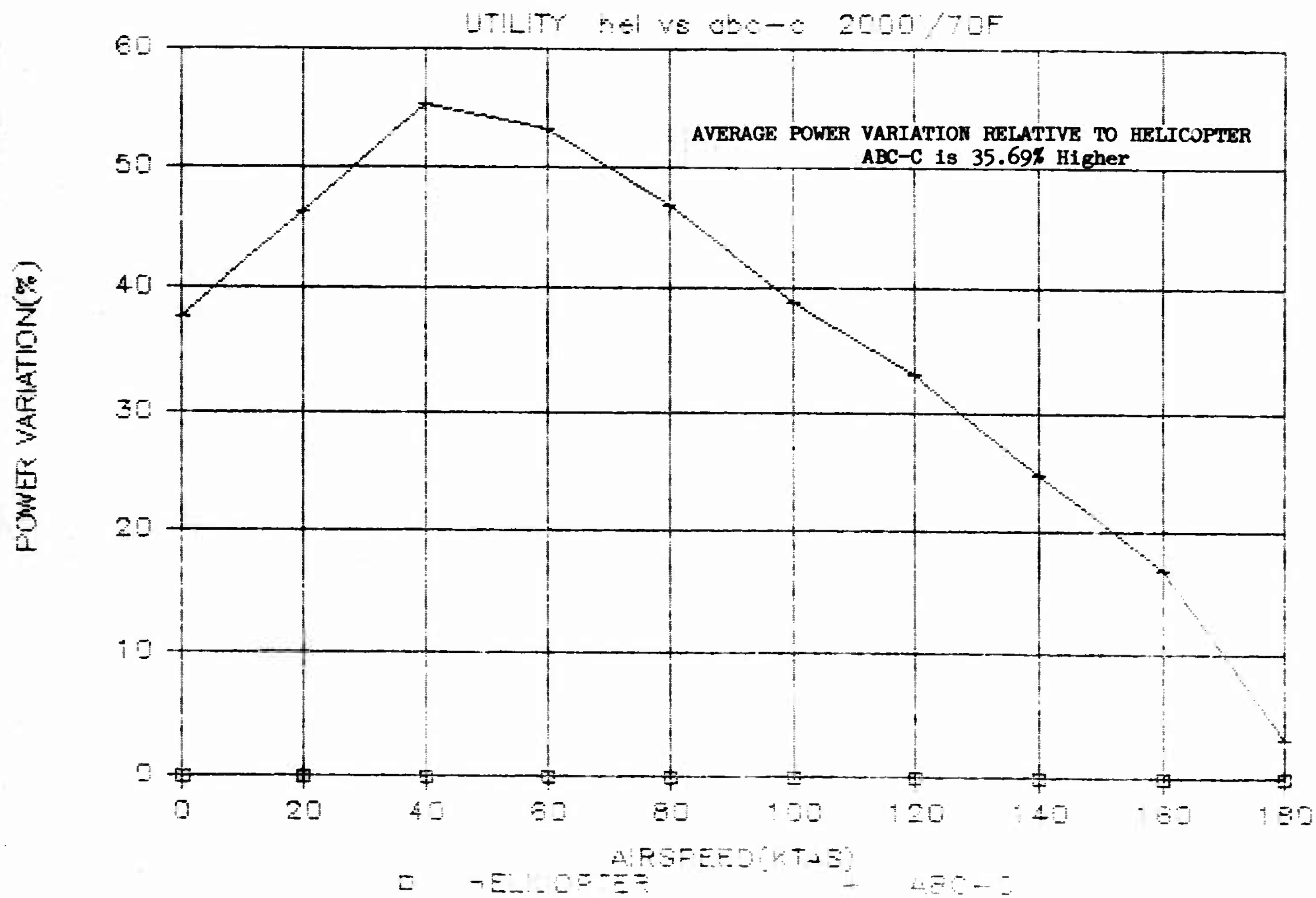

Figure N-VII-55. Utility power variation: helicopter and ABC-compound, 2,000'/70°F.

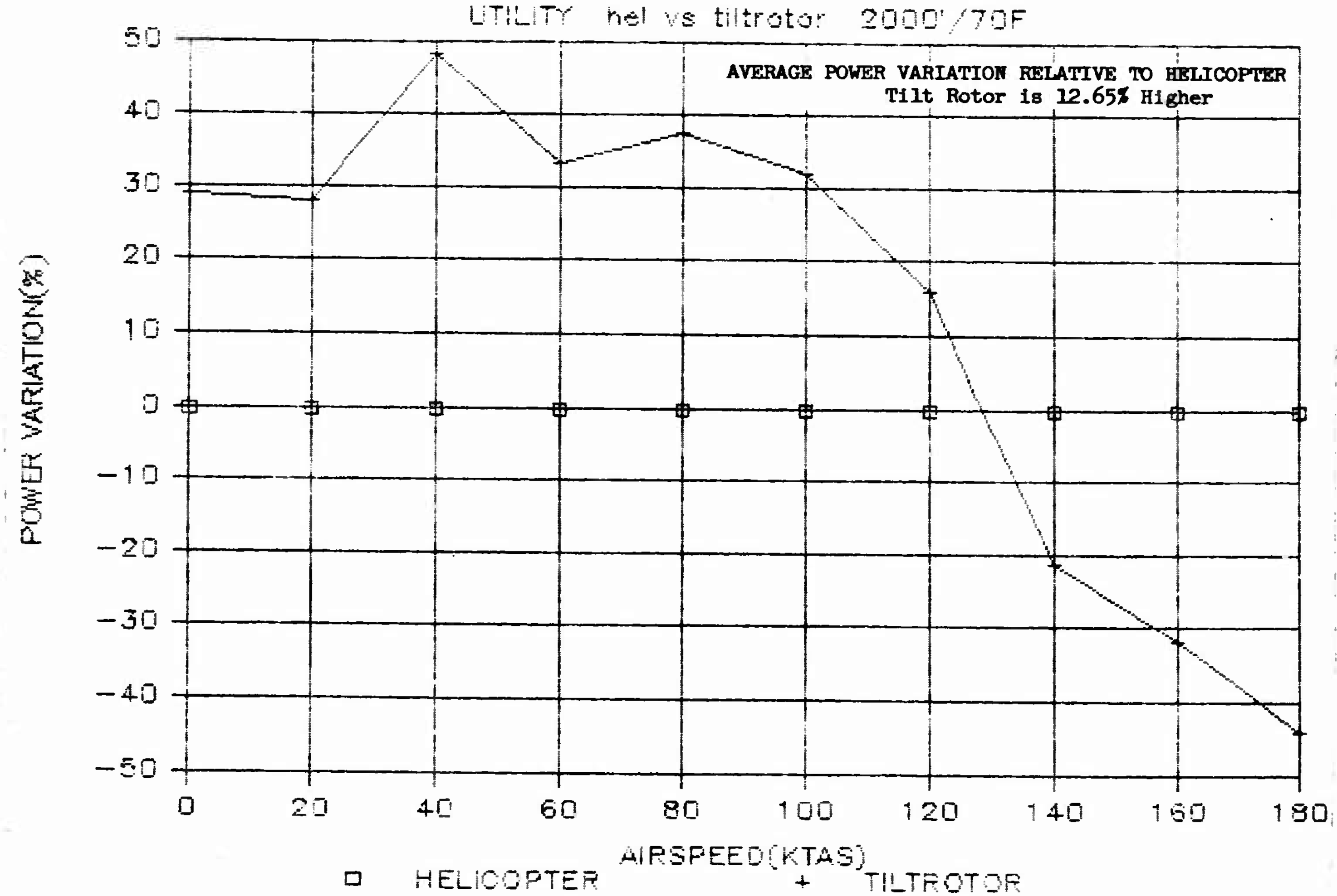

Figure N-VII-56. Utility power variation: helicopter and tilt rotor, 2,000'/70°F.

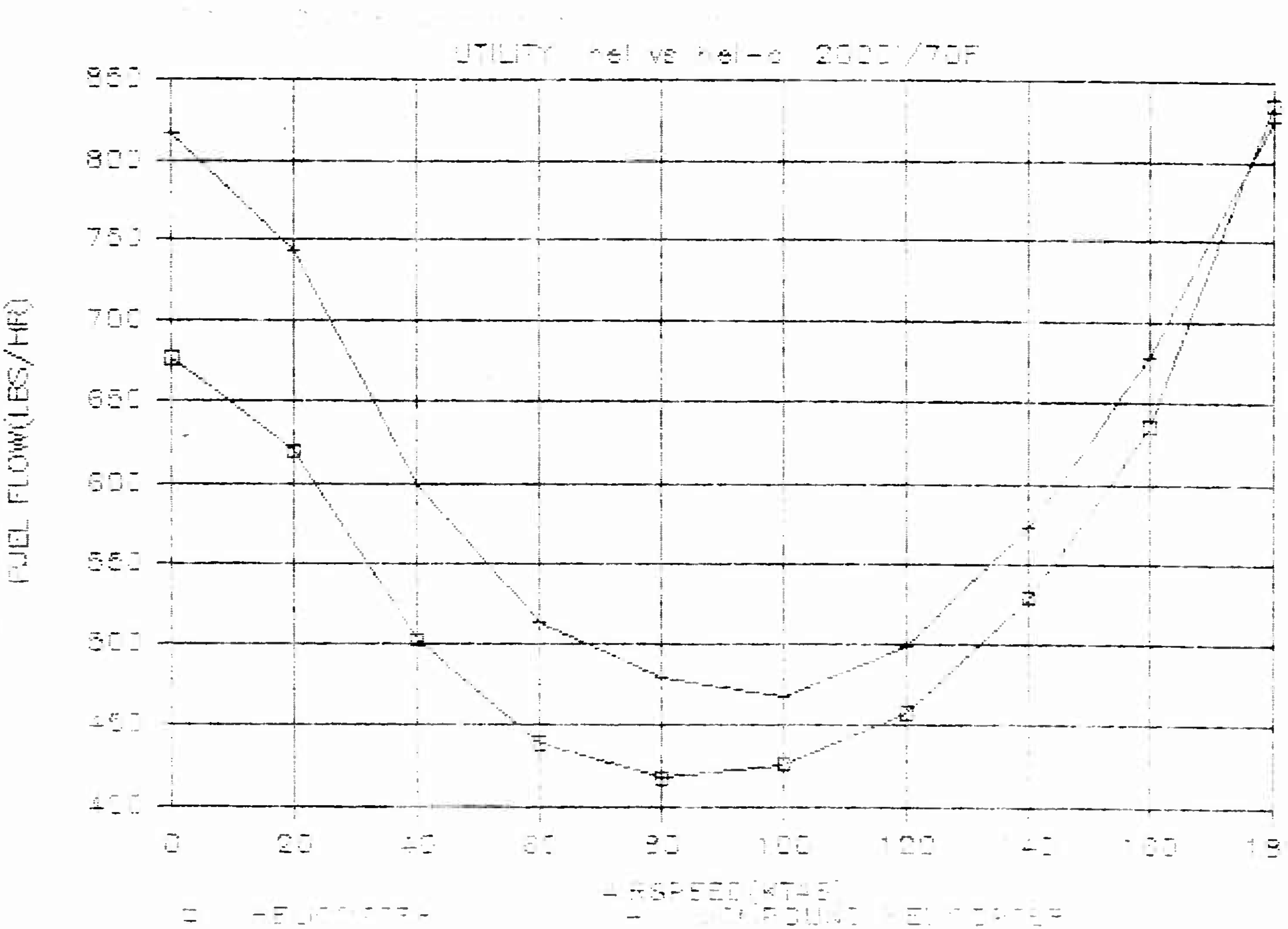

Figure N-VII-57. Utility fuel flow: helicopter and helicopter-compound, 2,000'/70°F.

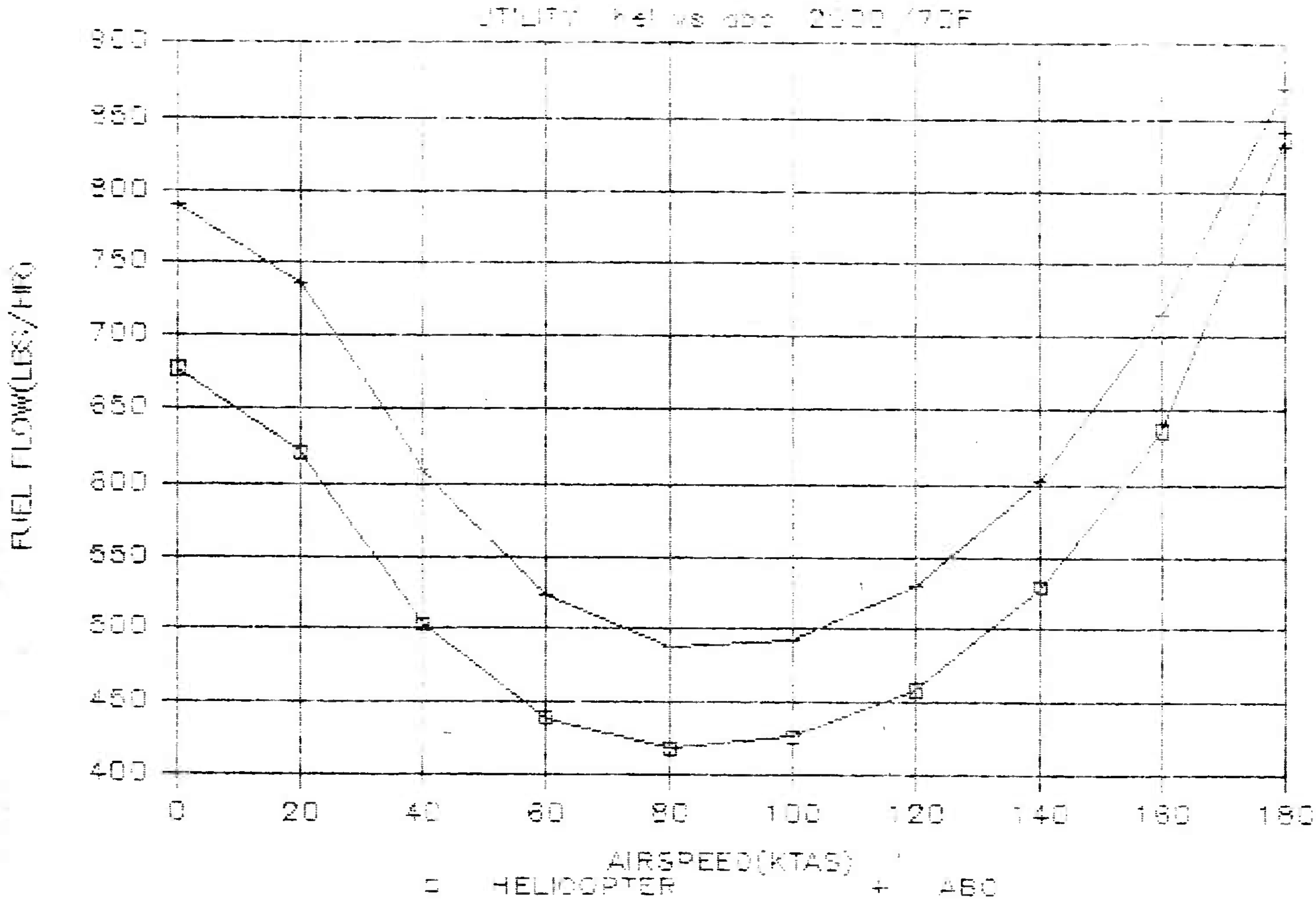

Figure N-VII-58. Utility fuel flow: helicopter and ABC, 2,000'/70°F.

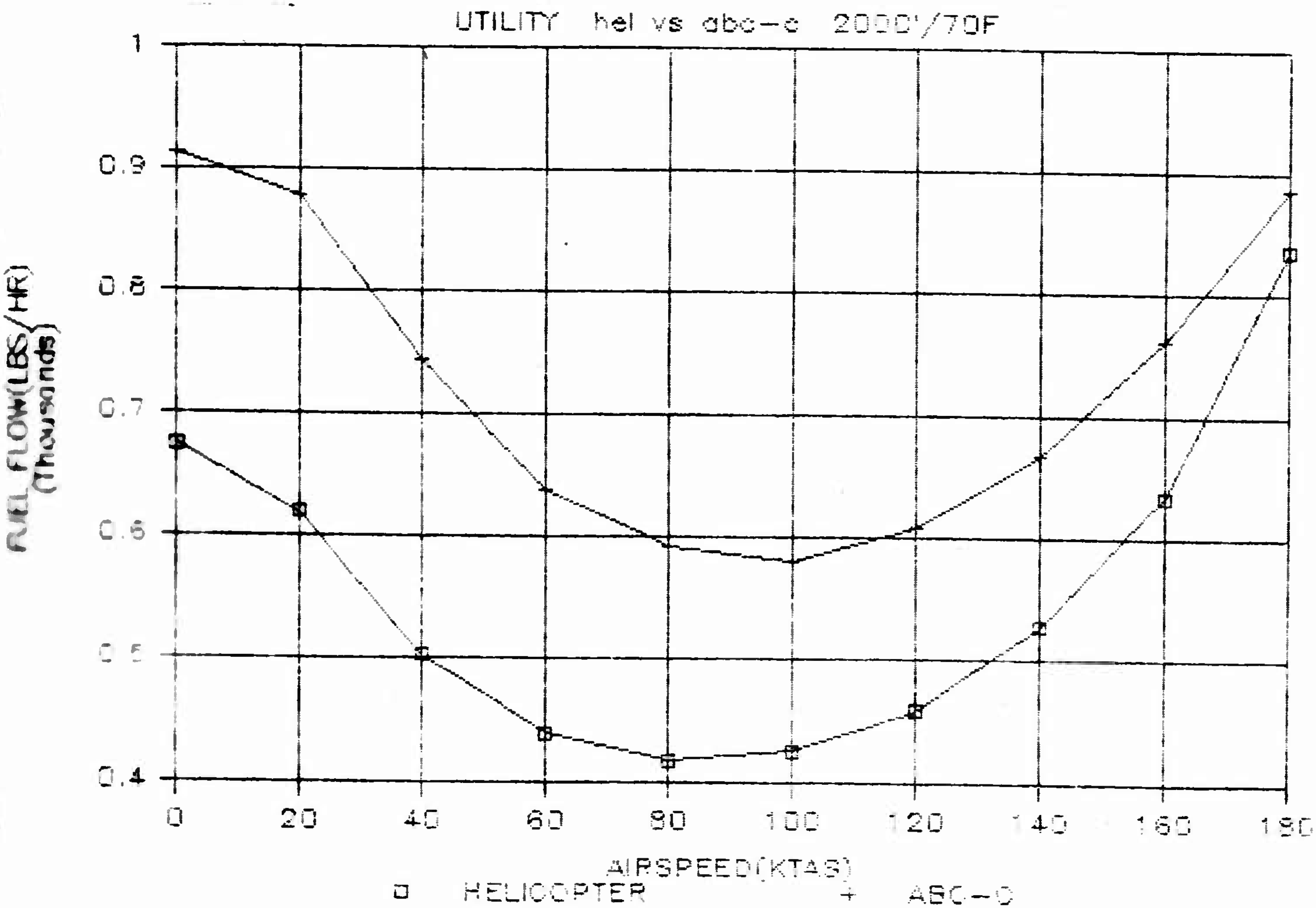

Figure N-VII-59. Utility fuel flow: helicopter and ABC-compound, 2,000'/70°F.

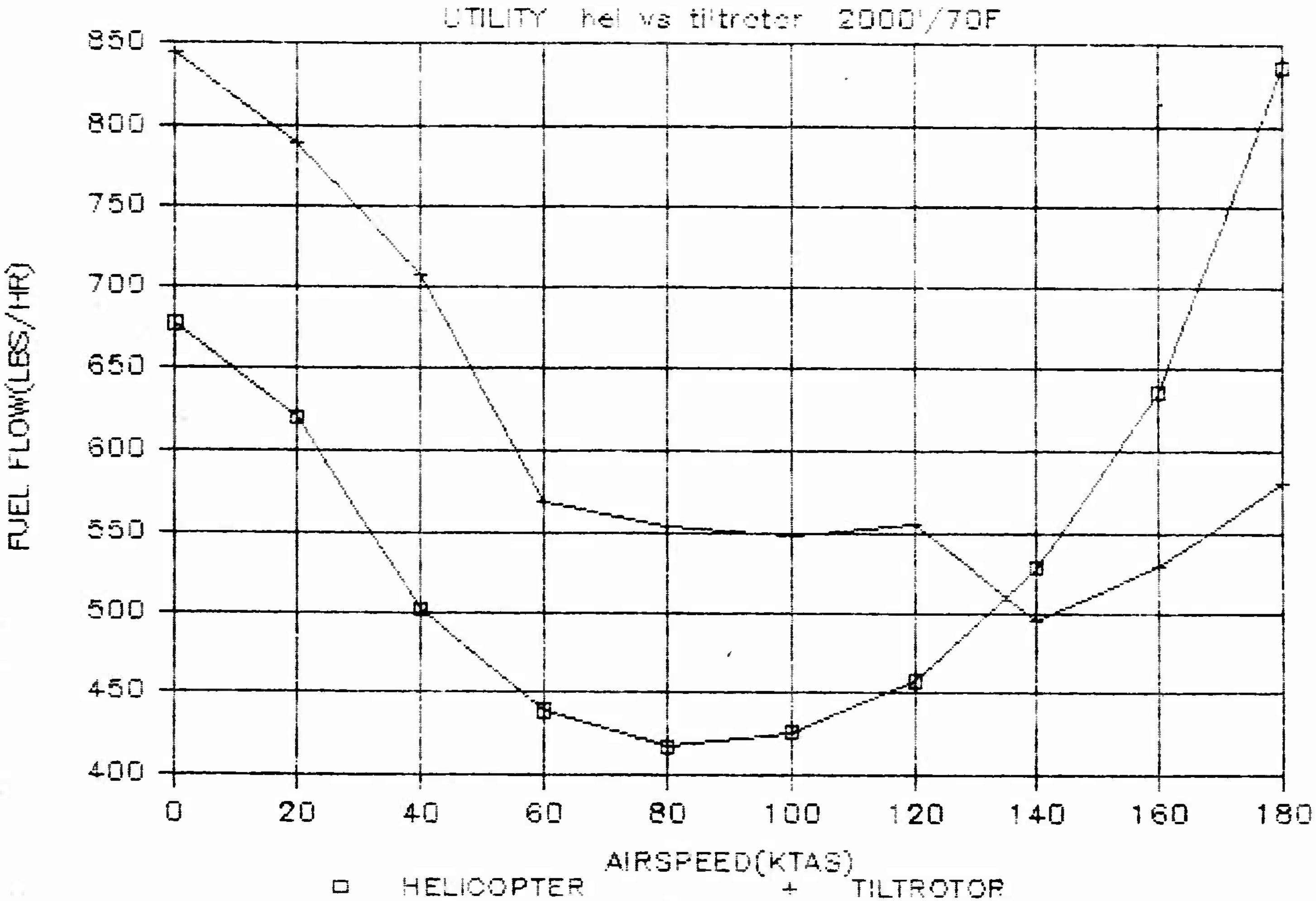

Figure N-VII-60. Utility fuel flow: helicopter and tilt rotor, 2,000'/70°F.

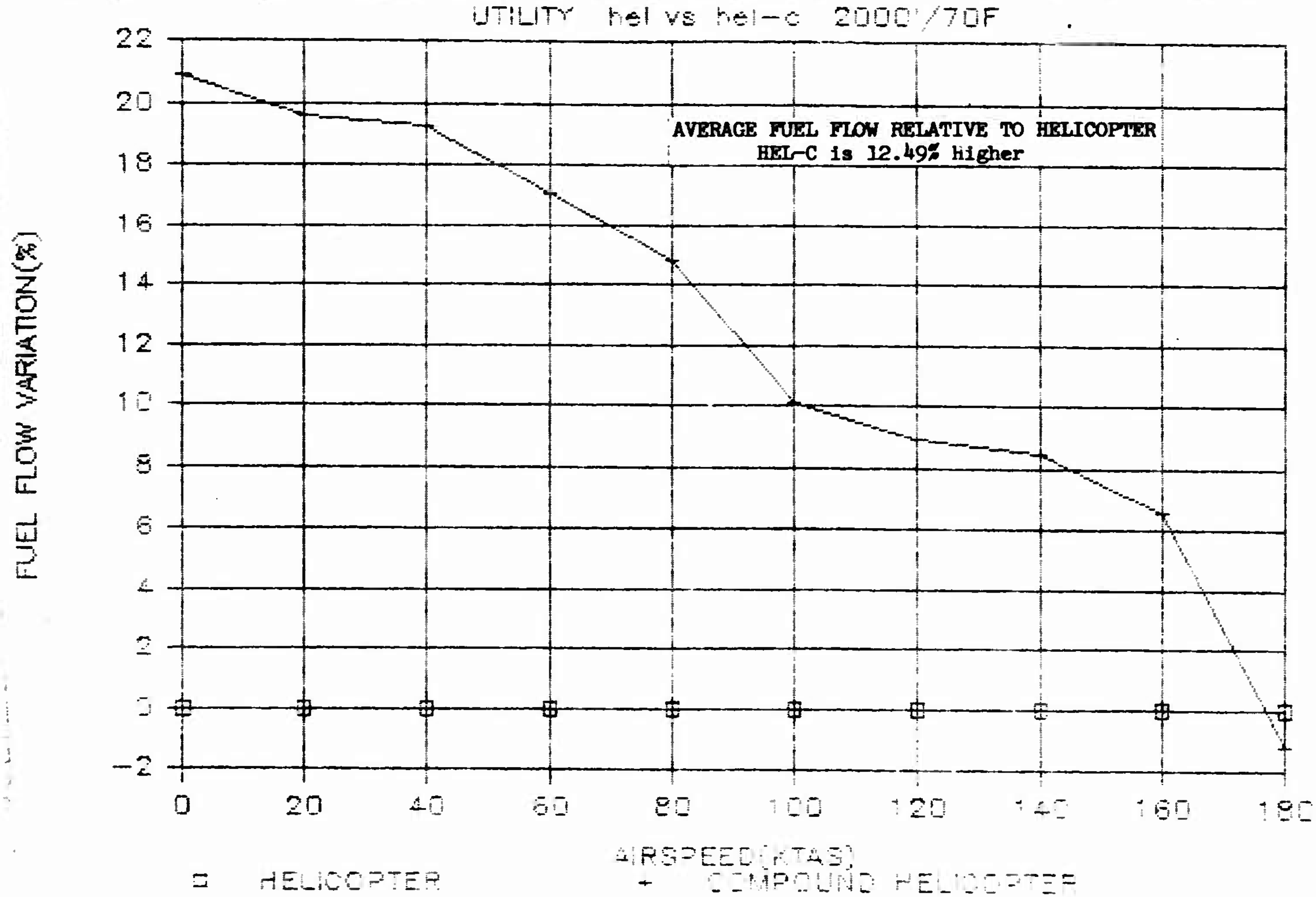

Figure N-VII-61. Utility fuel flow variation: helicopter and helicopter-compound, 2,000'/70°F.

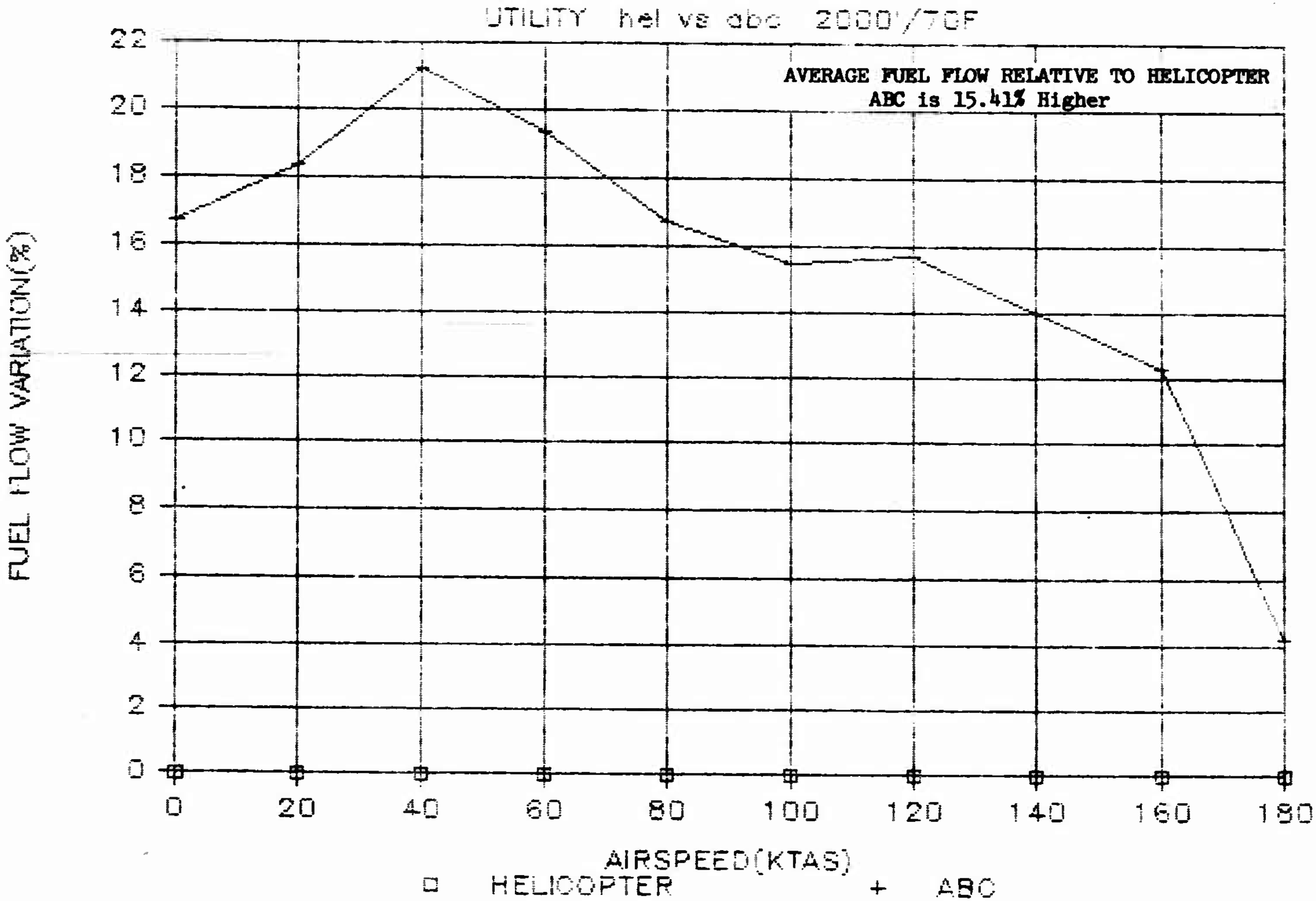

Figure N-VII-62. Utility fuel flow variation: helicopter and ABC, 2,000'/70°F.

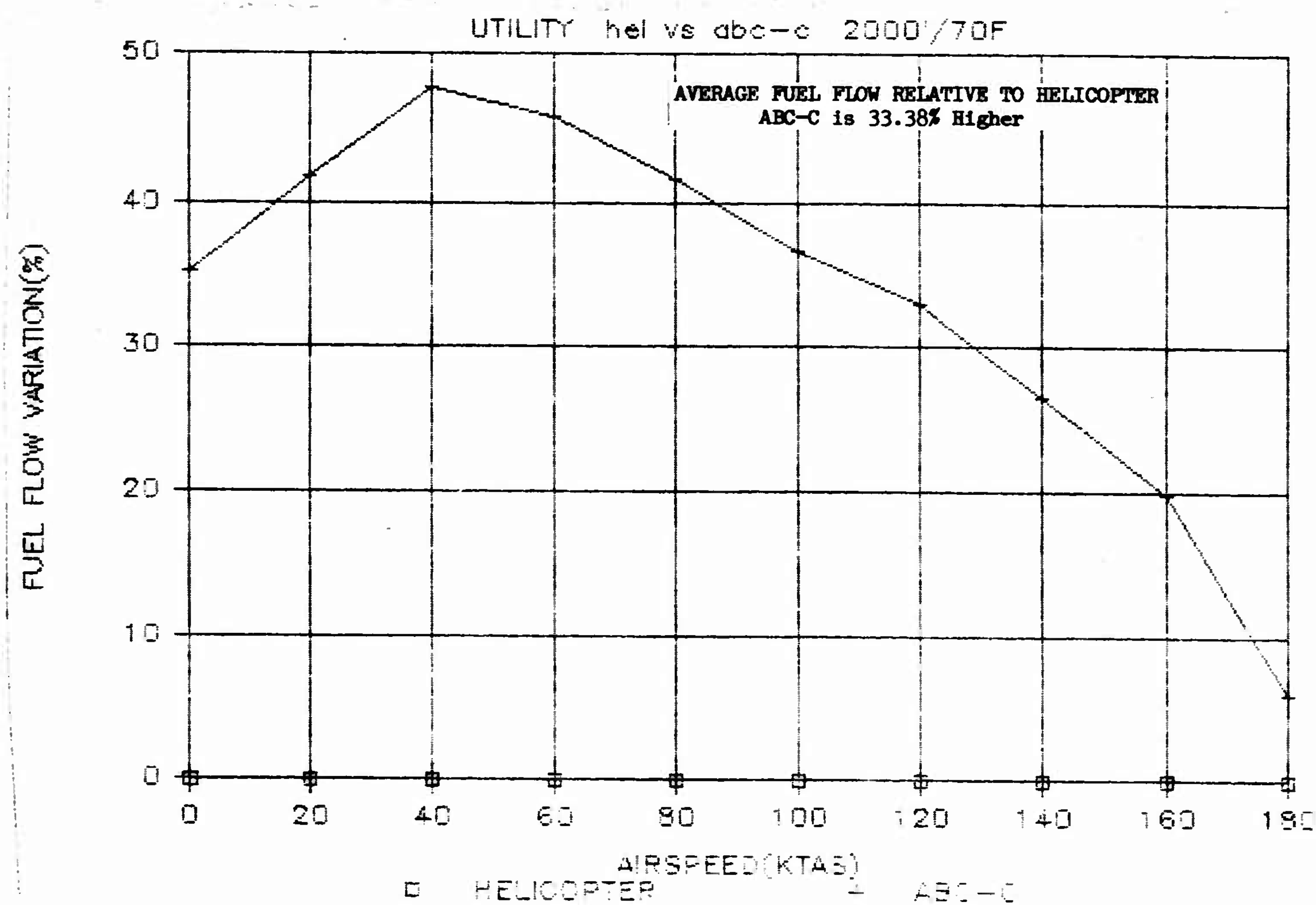

Figure N-VII-63. Utility fuel flow variation: helicopter and ABC-compound, 2,000'/70°F.

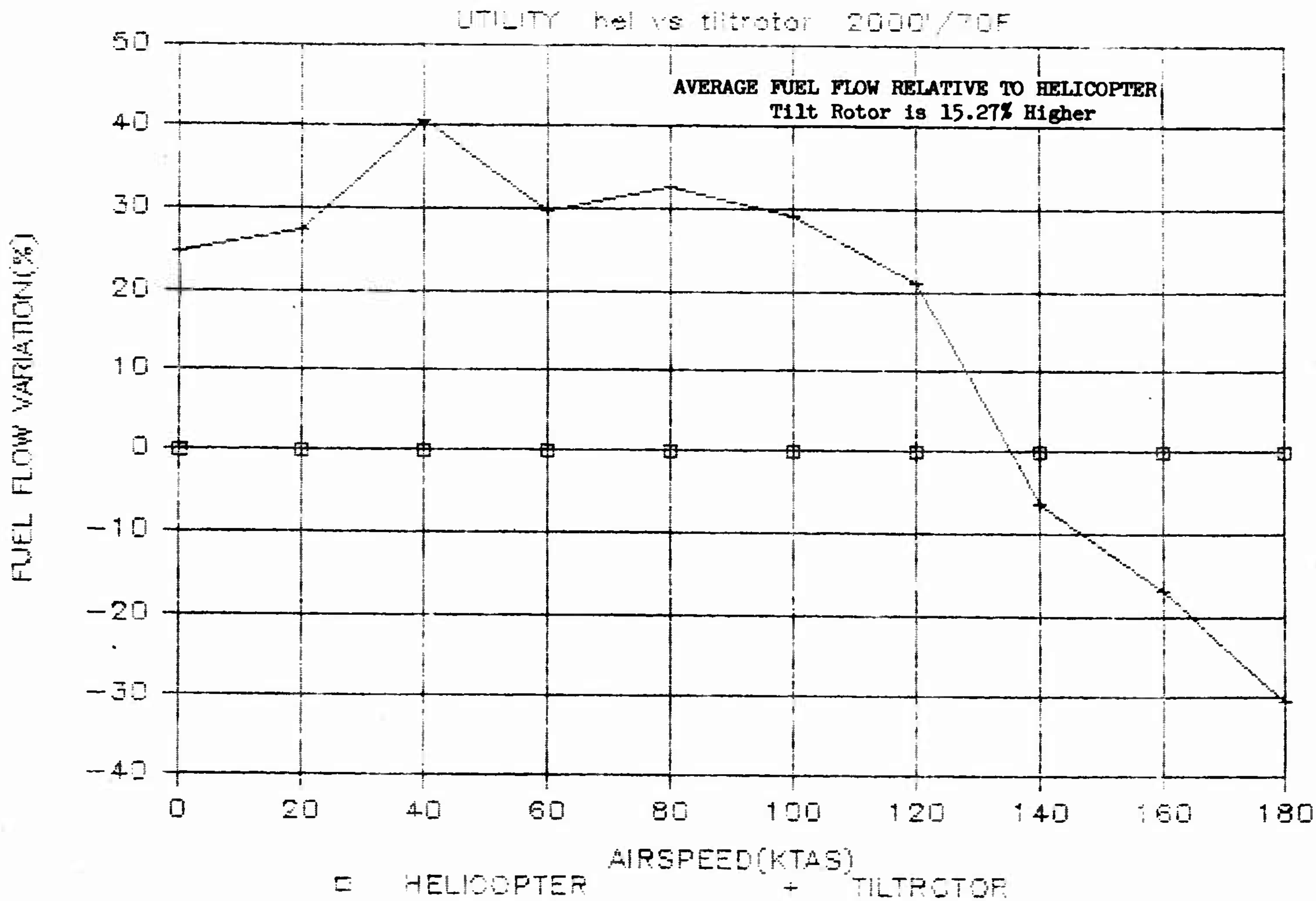

Figure N-VII-64. Utility fuel flow variation: helicopter and tilt rotor, 2,000'/70°F.

Table N-VII-8. LHX-Utility cruise efficiency, 2,000 ft/70°F.

AVERAGE PERCENT DIFFERENCE IN FUEL FLOW (0-180 KT)	
Configuration	Percent Difference
Helicopter	0
Compound Helicopter	12.49
ABC	15.41
Compound ABC	33.38
TR	15.27

N-VII-6. FINDINGS. The data presented in tables N-VII-1 through N-VII-8 is summarized in figures N-VII-65 and N-VII-66 relative to differential unit cost and indicates the following:

a. All configurations are less efficient than the helicopter relative to power, fuel flow, and cost.

b. In all cases, the compound ABC SCAT and Utility configurations are outliers and are indicative of either poor configurations relative to LHX requirements or an insufficient data base used in developing the designs.

c. The compound helicopter is the more efficient design.

N-VII-7. CONCLUSIONS.

a. The compound ABC should be dropped from consideration.

b. The ABC and compound helicopter should be dropped from consideration because they afford approximately the same speed potential as the helicopter but at a penalty in power, fuel consumption, and cost.

c. The TR should be retained for consideration until the wide margin in speed capability is thoroughly explored.

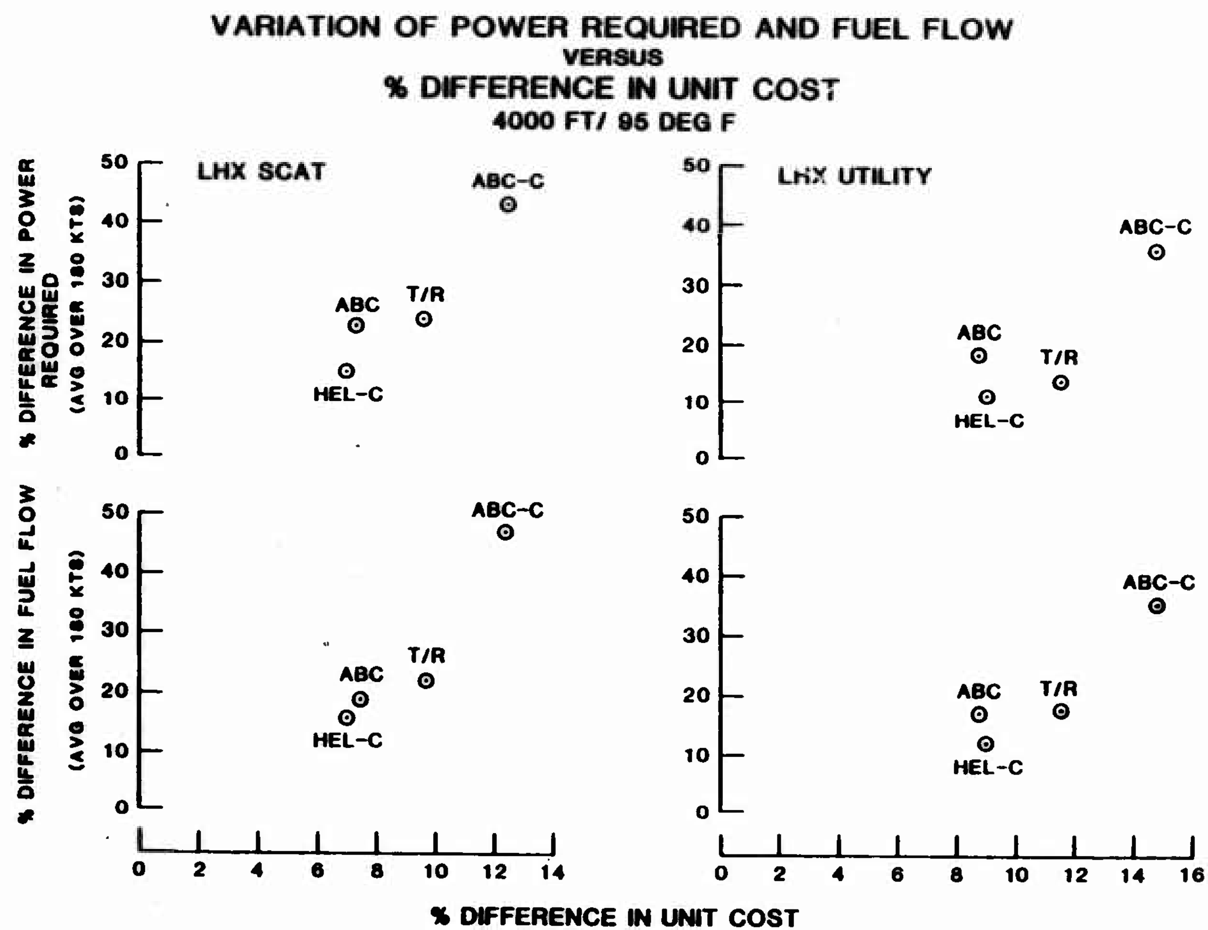

Figure N-VII-65. Power required and fuel flow summary: 4,000'/95°F.

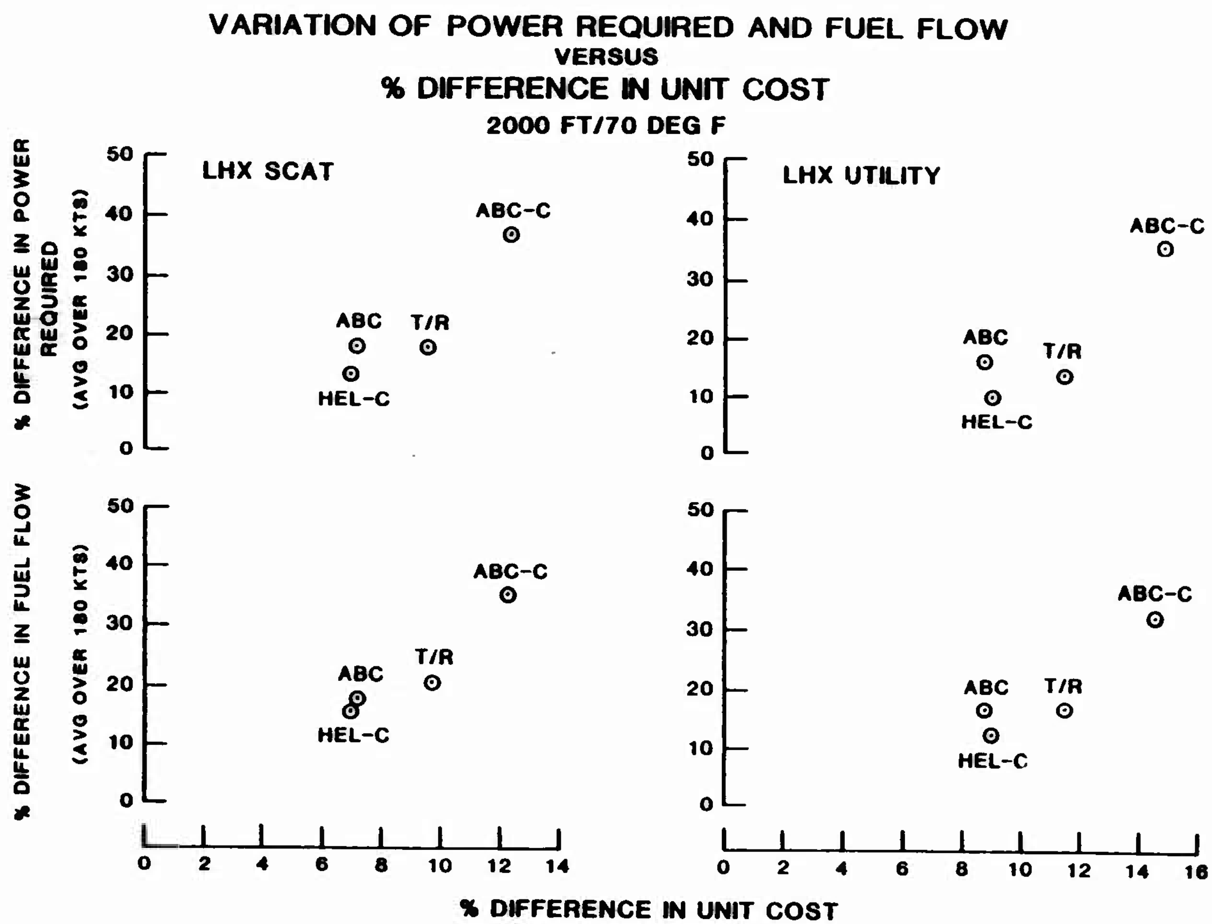

Figure N-VII-66. Power required and fuel flow summary: 2,000'/70°F.

ANNEX VIII TO APPENDIX N

LEVEL FLIGHT ANALYSIS-ONE ENGINE INOPERATIVE (OEI)

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ANNEX VIII TO APPENDIX N
LEVEL FLIGHT ANALYSIS-ONE ENGINE INOPERATIVE (OEI)

N-VIII-1. PURPOSE. This section of the level flight analysis will examine the single-engine operational constraints regarding the ability of the Light Helicopter Family (LHX) candidate to maintain en route capability.

N-VIII-2. BACKGROUND. Based on previous decisions made on the basis of safety and survivability, the LHX is to be produced with two engines.

N-VIII-3. LIMITATIONS.

a. This section will address Scout-Attack (SCAT) and Utility candidates of new design rotorcraft.

b. The condition to be examined is 4,000 feet (ft)/95° Fahrenheit (F).

c. Comparisons will be made at the design gross weight value.

N-VIII-4. METHODOLOGY. The methodology consists of determining the interval, if any, at which each candidate can maintain level flight. The intent is to determine if any specific candidate has a distinct advantage. In addition, an assessment is made as to the merits of an emergency rating for the engine. In addition, an evaluation is made to determine if the LHX can transition from level flight to a hover in ground effect (HIGE) condition to effect a landing. The level of offloading necessary to effect the transition/landing is presented.

N-VIII-5. RESULTS/ANALYSIS.

a. 4,000 ft/95°F.

(1) SCAT. Individual plots depicting the power required and single-engine power available for each configuration are presented in figures N-VIII-1 through N-VIII-5. The data is presented for the trade-off determination (TOD) design gross weight. The single-engine power available is from TOD data and shows some (little) increase in power available from ram. The OEI results are shown in table N-VIII-1.

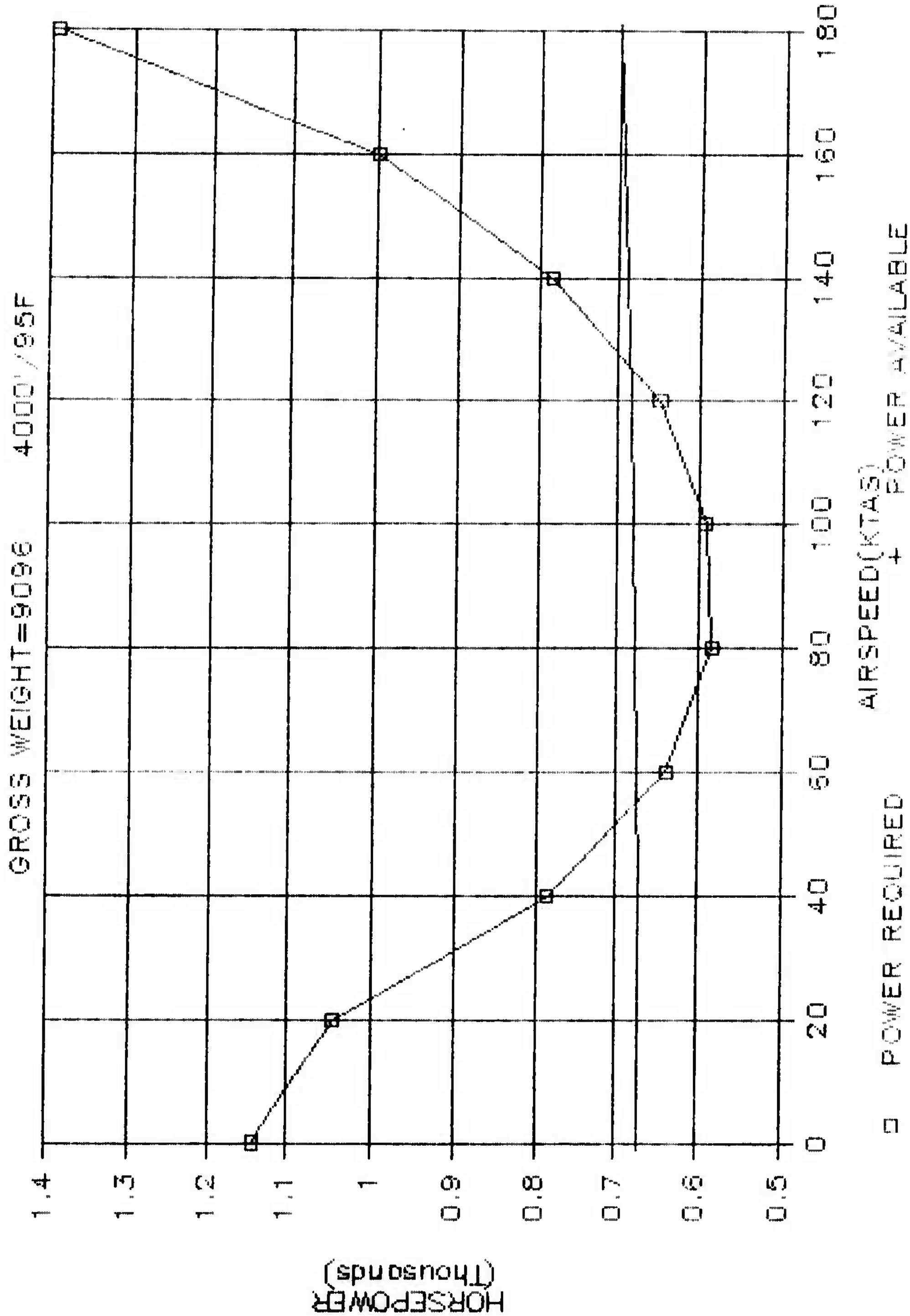

Figure N-VIII-1. SCAT helicopter OEI: 4,000'/95°F.

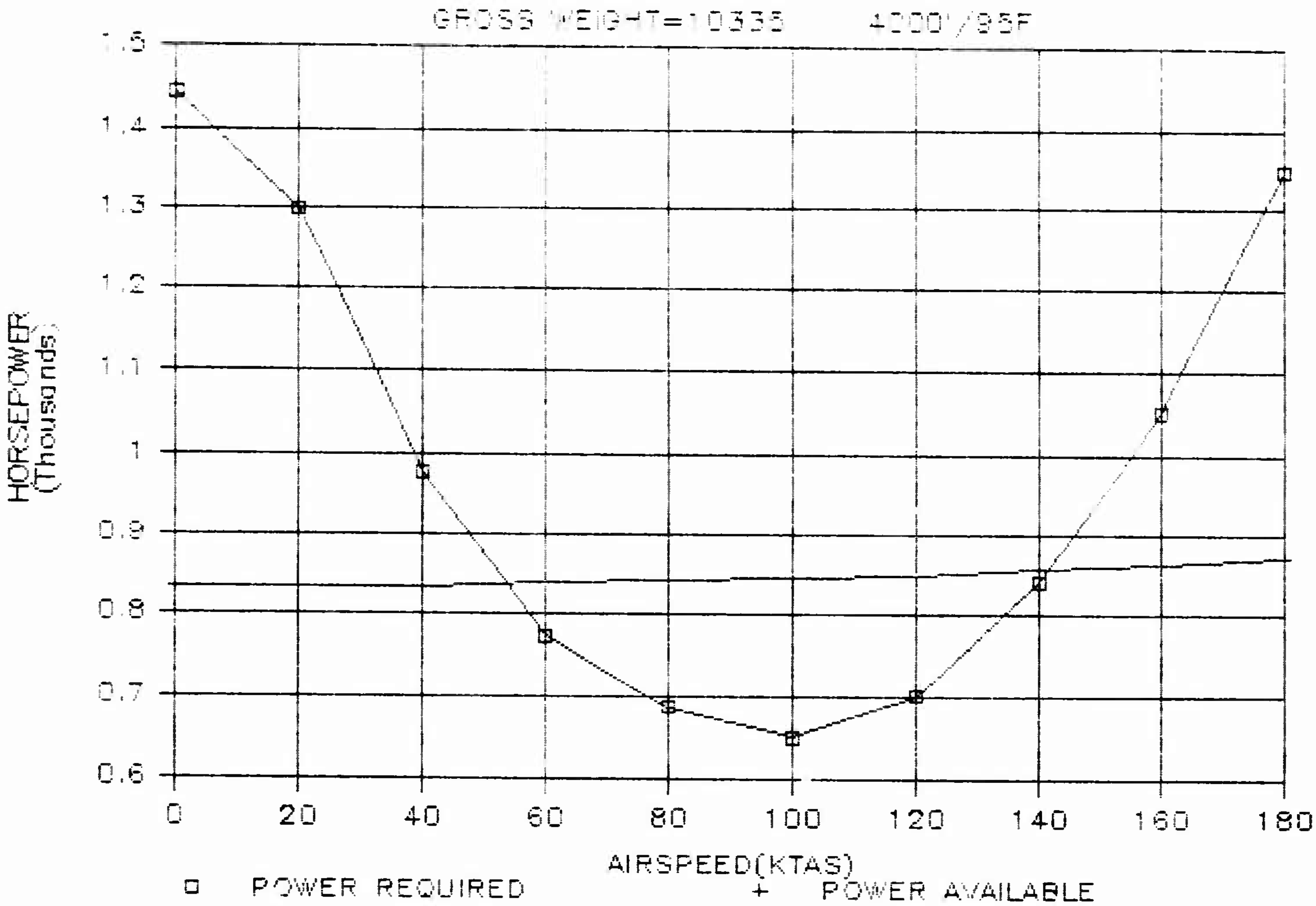

Figure N-VIII-2. SCAT helicopter-compound OEI: 4,000'/95°F.

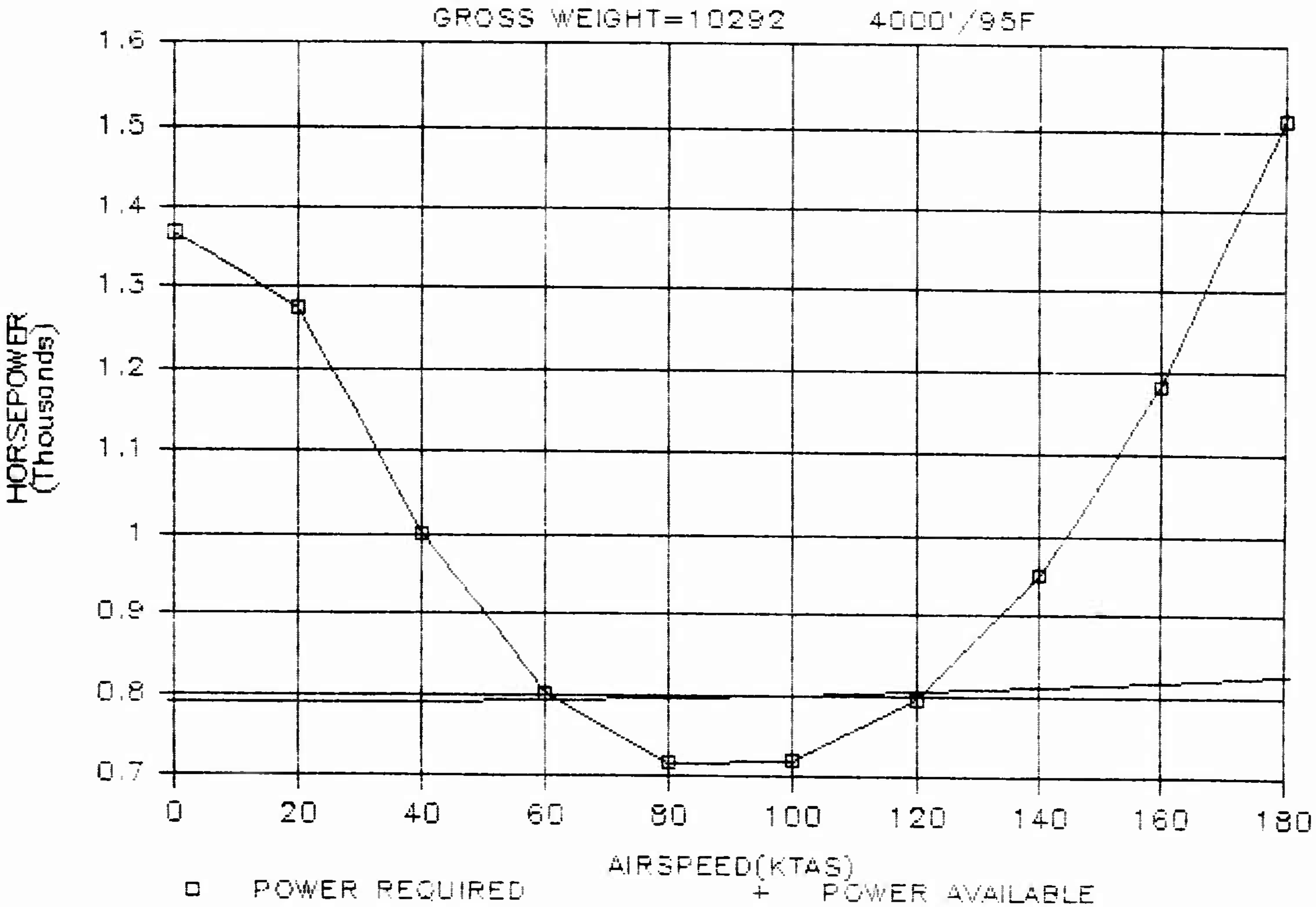

Figure N-VIII-3. SCAT ABC OEI: 4,000'/95°F.

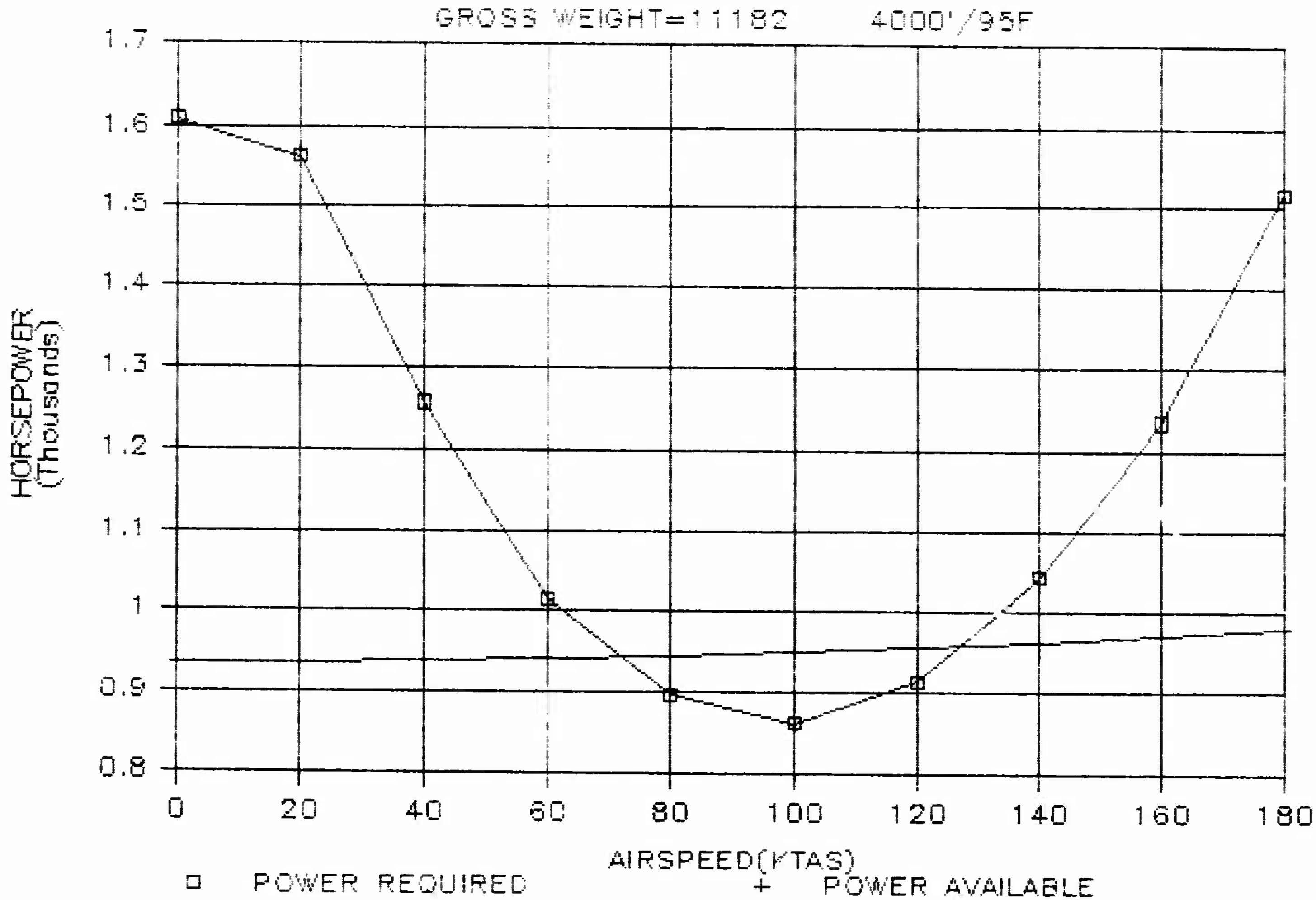

Figure N-VIII-4. SCAT ABC-compound OEI: 4,000'/95°F.

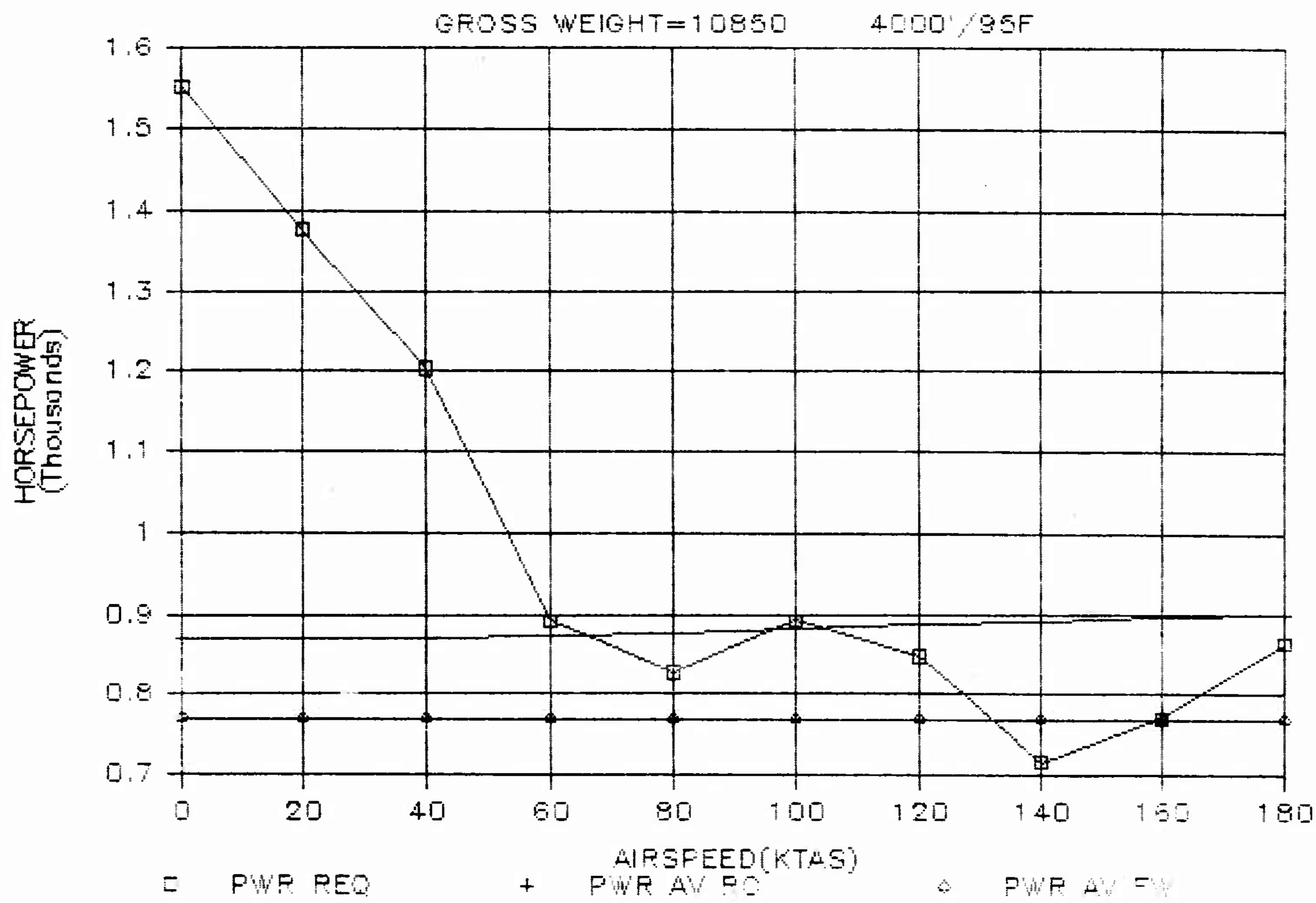

Figure N-VIII-5. SCAT tilt rotor OEI: 4,000'/95°F.

Table N-VIII-1. En route single-engine capability: SCAT at 4,000 ft, 95°F/LHX TOD baseline designs.

Configuration	Single-Engine Airspeed Range (knots (kt))	Gross Weight (pounds (lb))	Installed Engine Power (IRP at SLS)*
Helicopter	55-125	9,096	959
Compound Helicopter	33-146	10,335	1,191
Advancing Blade Concept (ABC)	62-121	10,292	1,131
Compound ABC	72-127	11,182	1,339
Tilt rotor (TR)			
Helicopter Mode	66-100+	10,850	1,244
Conversion Mode	100-140		
Fixed Wing (FW) Mode	66-181		

*Intermediate rated power at sea level standard.

(2) Utility. Individual plots presenting power required and single-engine power available for the Utility are presented in figures N-VIII-6 through N-VIII-10. The power available for a specific configuration is the same as that shown for the SCAT version of that configuration. The OEI results are presented in table N-VIII-2.

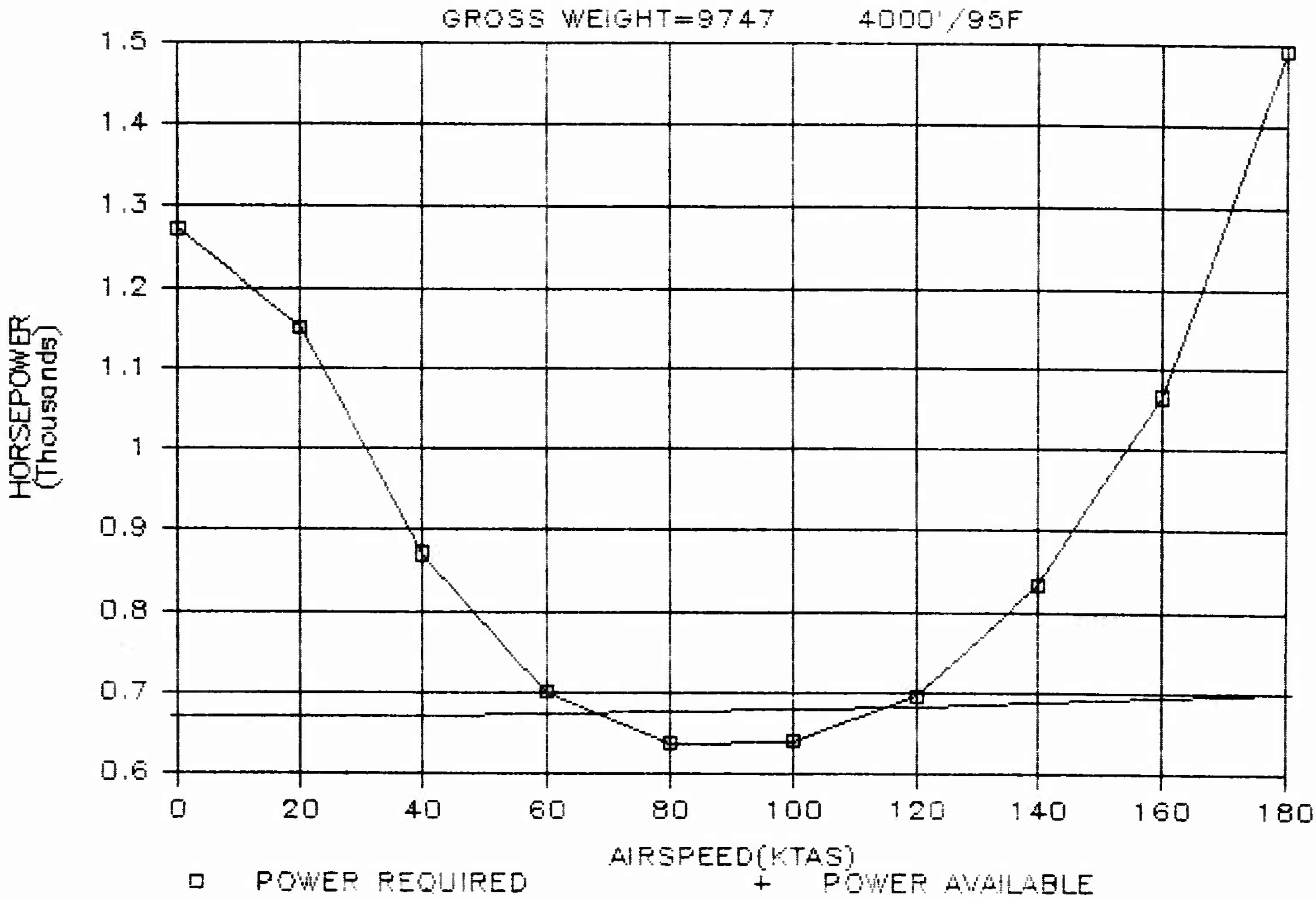

Figure N-VIII-6. Utility helicopter OEI: 4,000'/95°F.

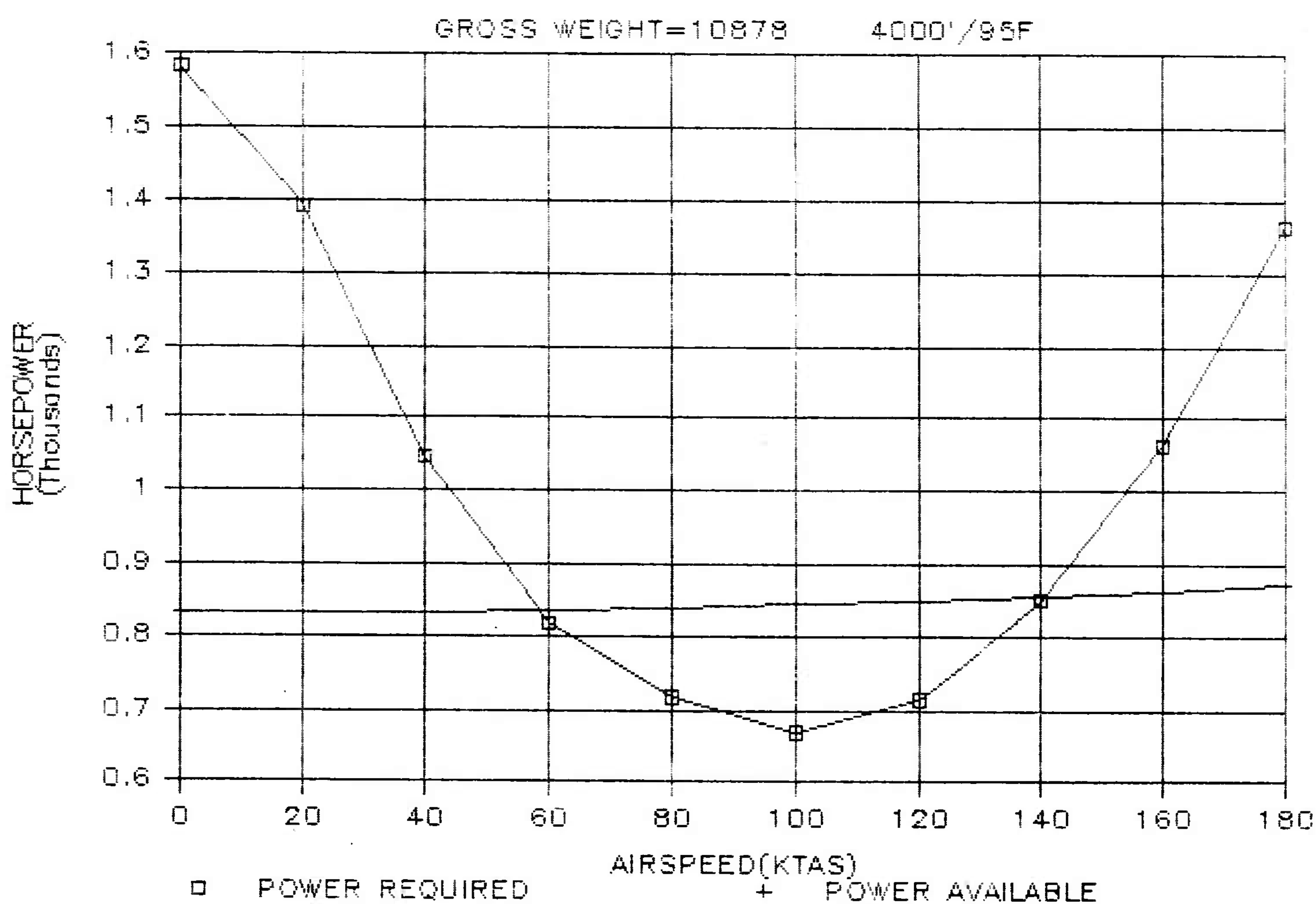

Figure N-VIII-7. Utility helicopter-compound OEI: 4,000'/95°F.

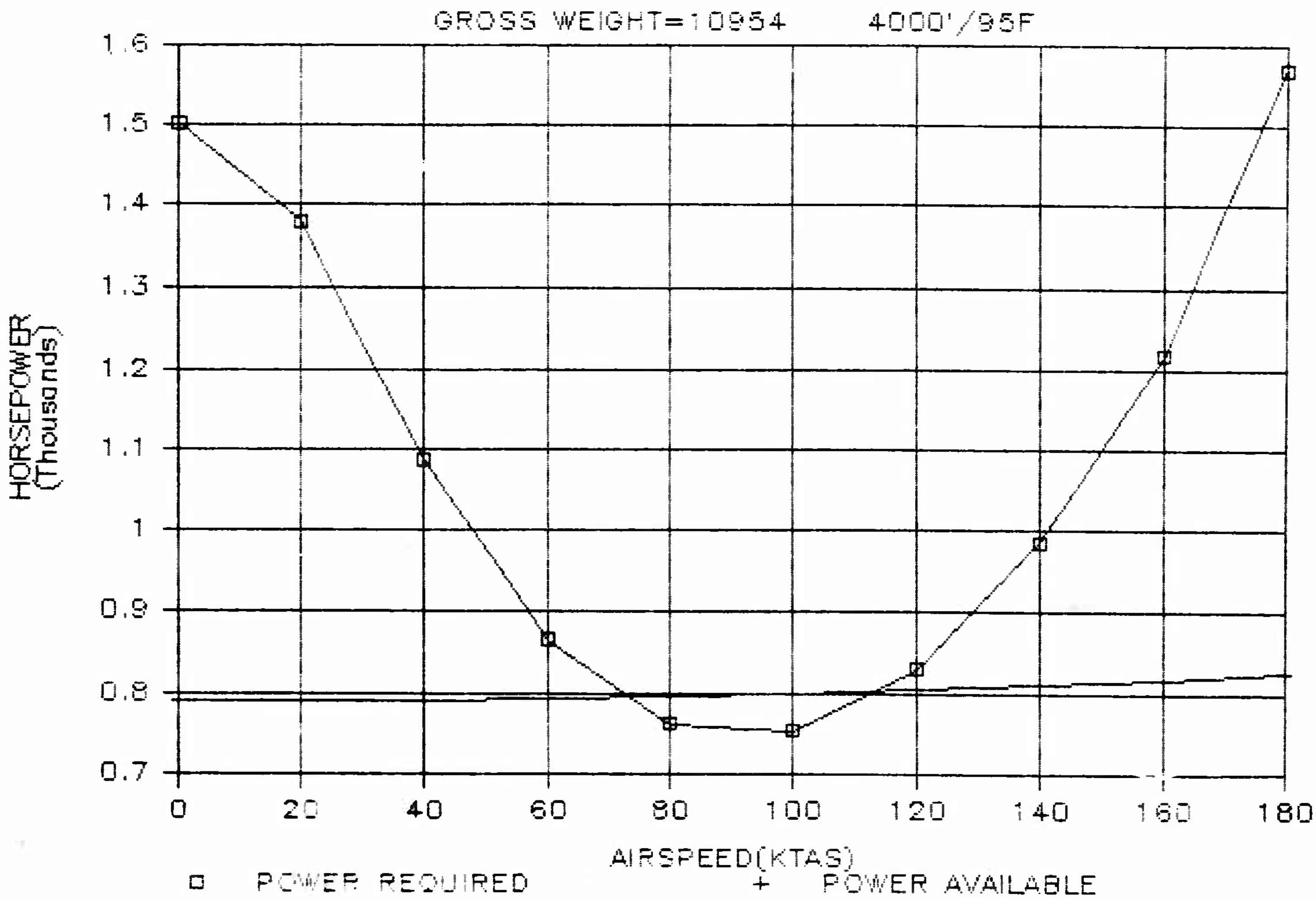

Figure N-VIII-8. Utility ABC OEI: 4,000'/95°F.

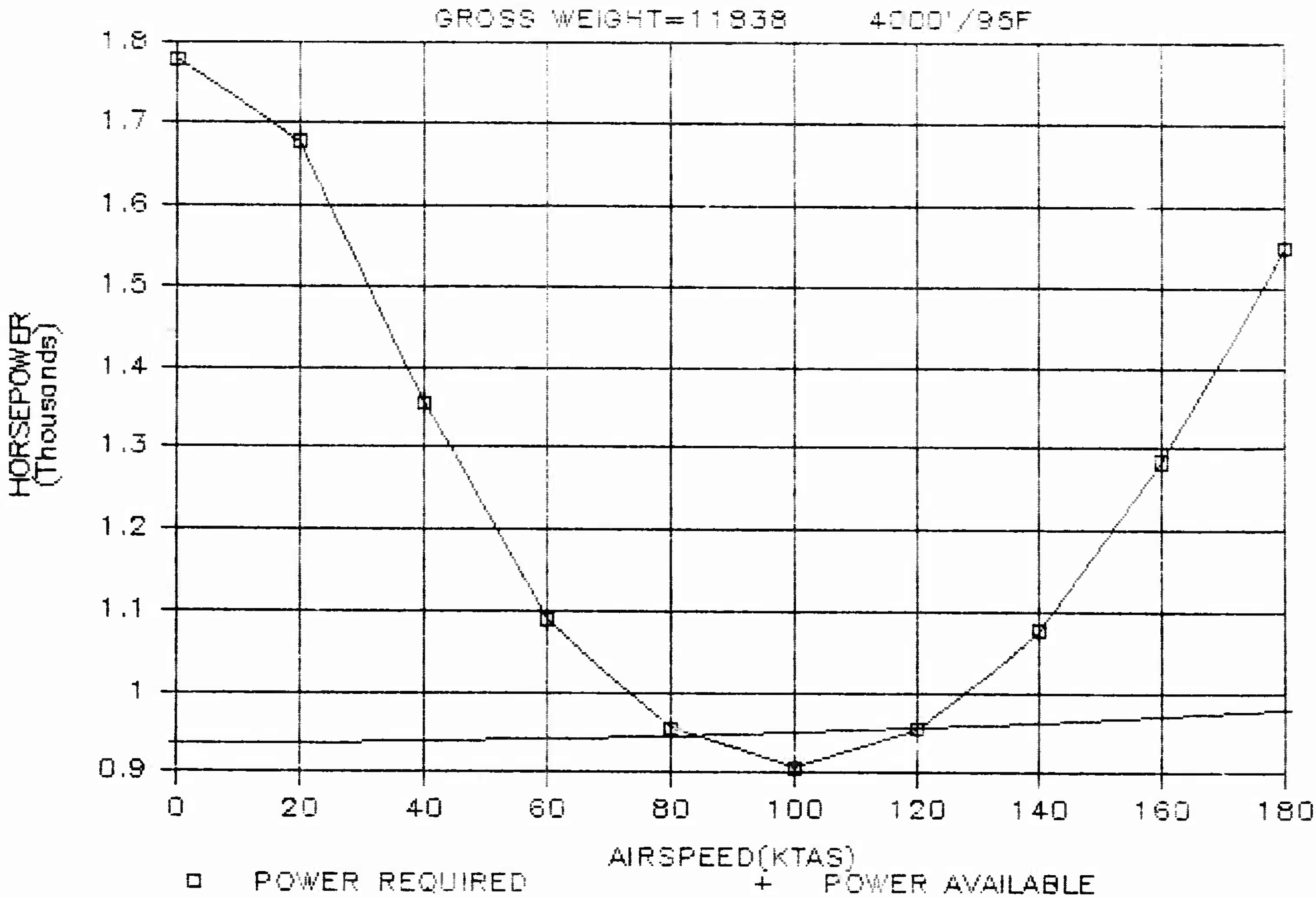

Figure N-VIII-9. Utility ABC-compound OEI: 4,000'/95°F.

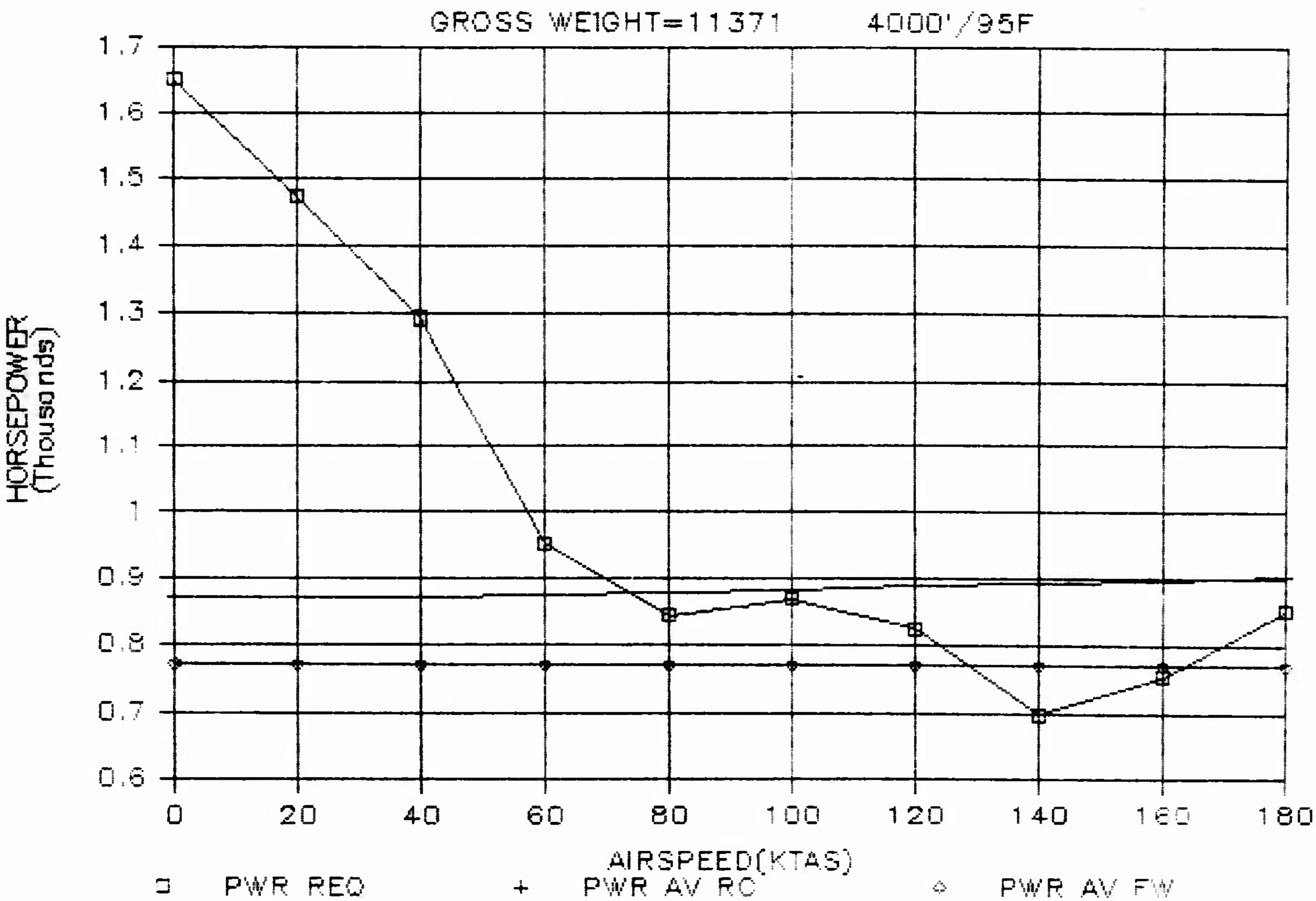

Figure N-VIII-10. Utility tilt rotor OEI: 4,000'/95°F.

Table N-VIII-2. En route single-engine capability: Utility at 4,000 ft, 95°F/LHX TOD baseline designs.

Configuration	Single-Engine Airspeed Range (kt)	Gross Weight (lb)	Installed Engine Power (IRP at SLS)
Helicopter	68-116	9,747	959
Compound Helicopter	58-141	10,878	1,191
ABC	72-112	10,954	1,131
Compound ABC	84-120	11,838	1,339
TR			
Helicopter Mode	74-100+	11,371	1,244
Conversion Mode	100-140		
FW Mode	74-182		

b. 2,000 ft/70°F.

(1) SCAT. Off-design ambient condition performance capabilities for the SCAT are presented in figures N-VIII-11 through N-VIII-15. The data presented is for the design gross weights. The single-engine results are presented in table N-VIII-3.

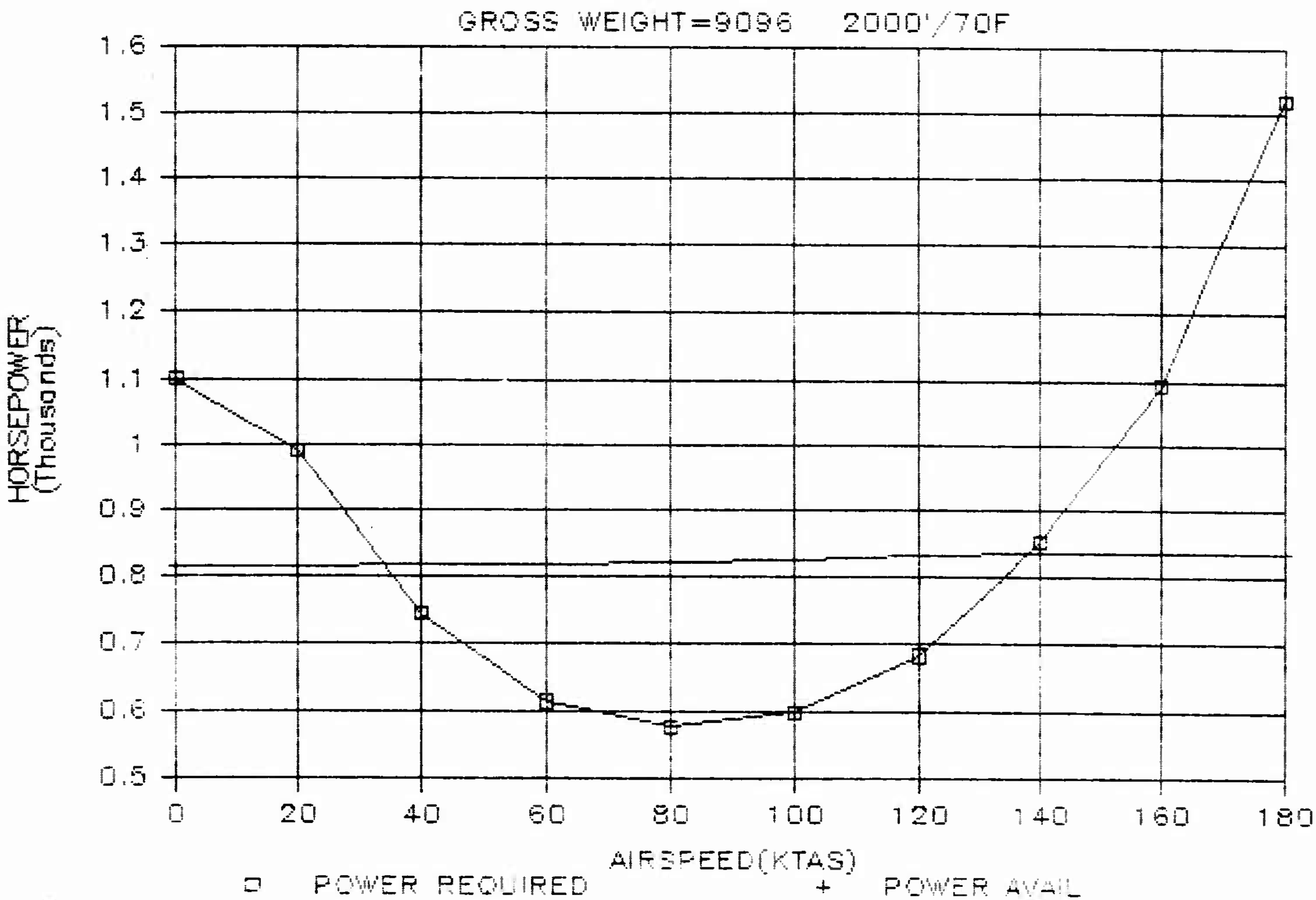

Figure N-VIII-11. SCAT helicopter OEI: 2,000'/70°F.

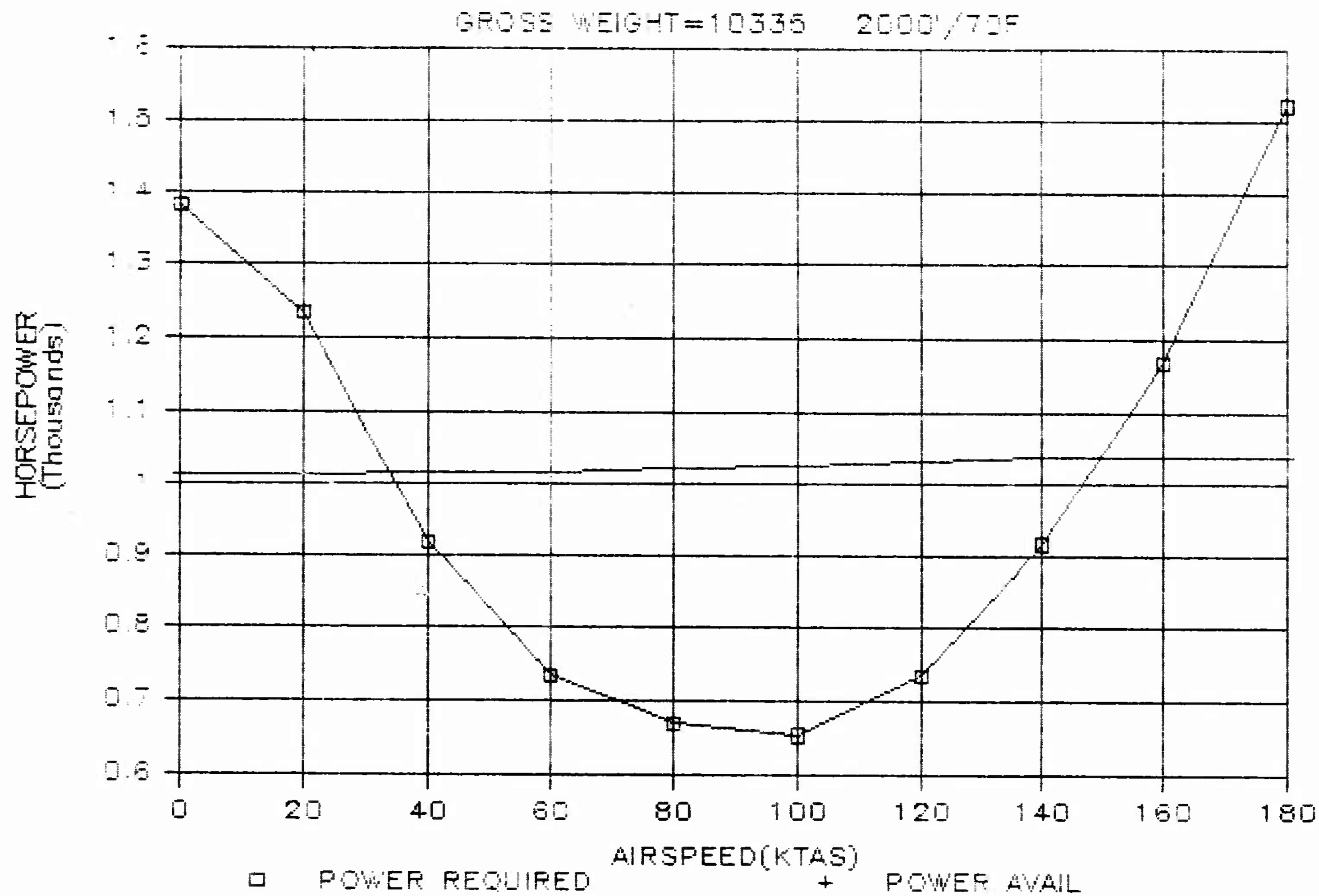

Figure N-VIII-12. SCAT helicopter-compound OEI: 2,000'/70°F.

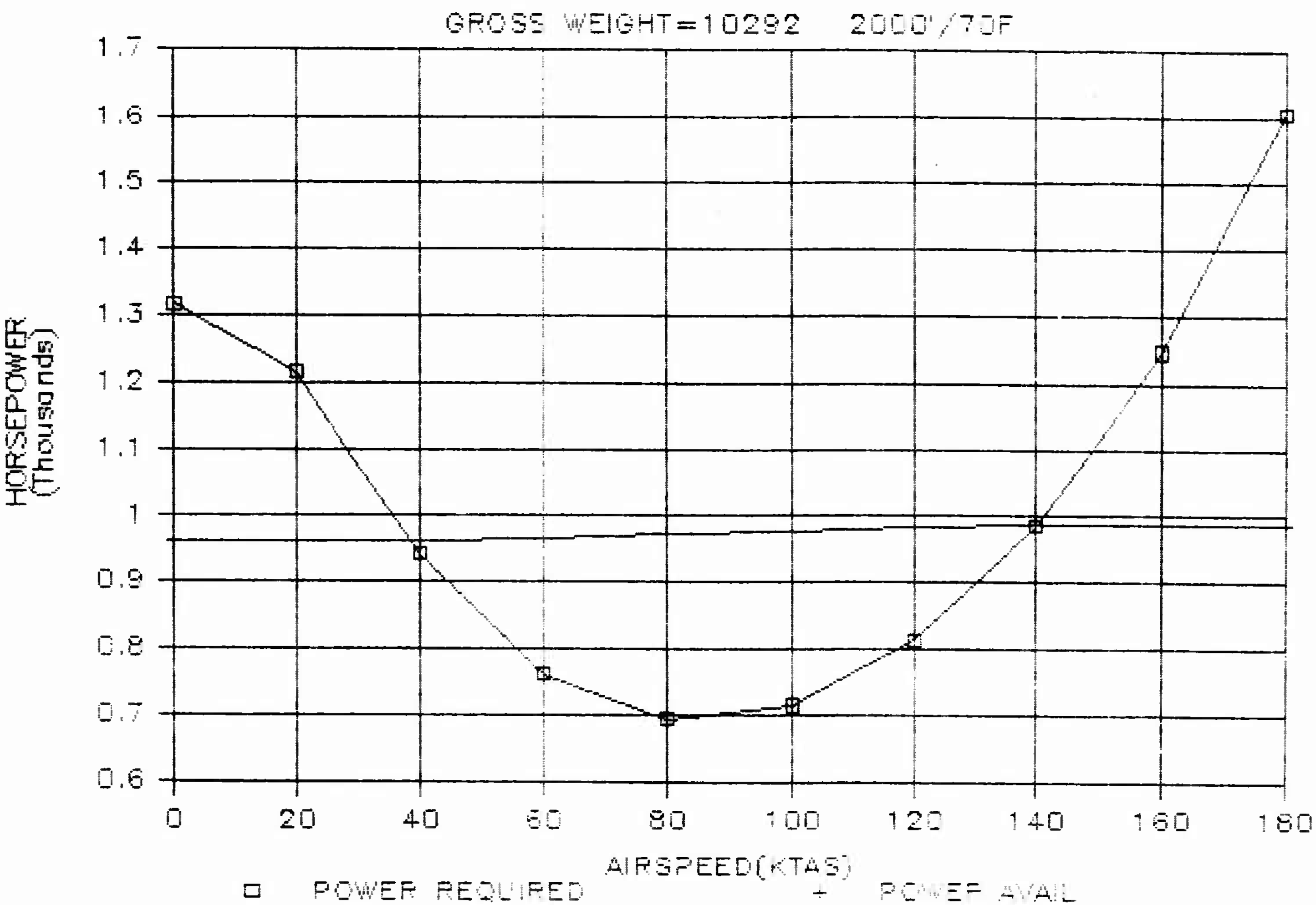

Figure N-VIII-13. SCAT ABC OEI: 2,000'/70°F.

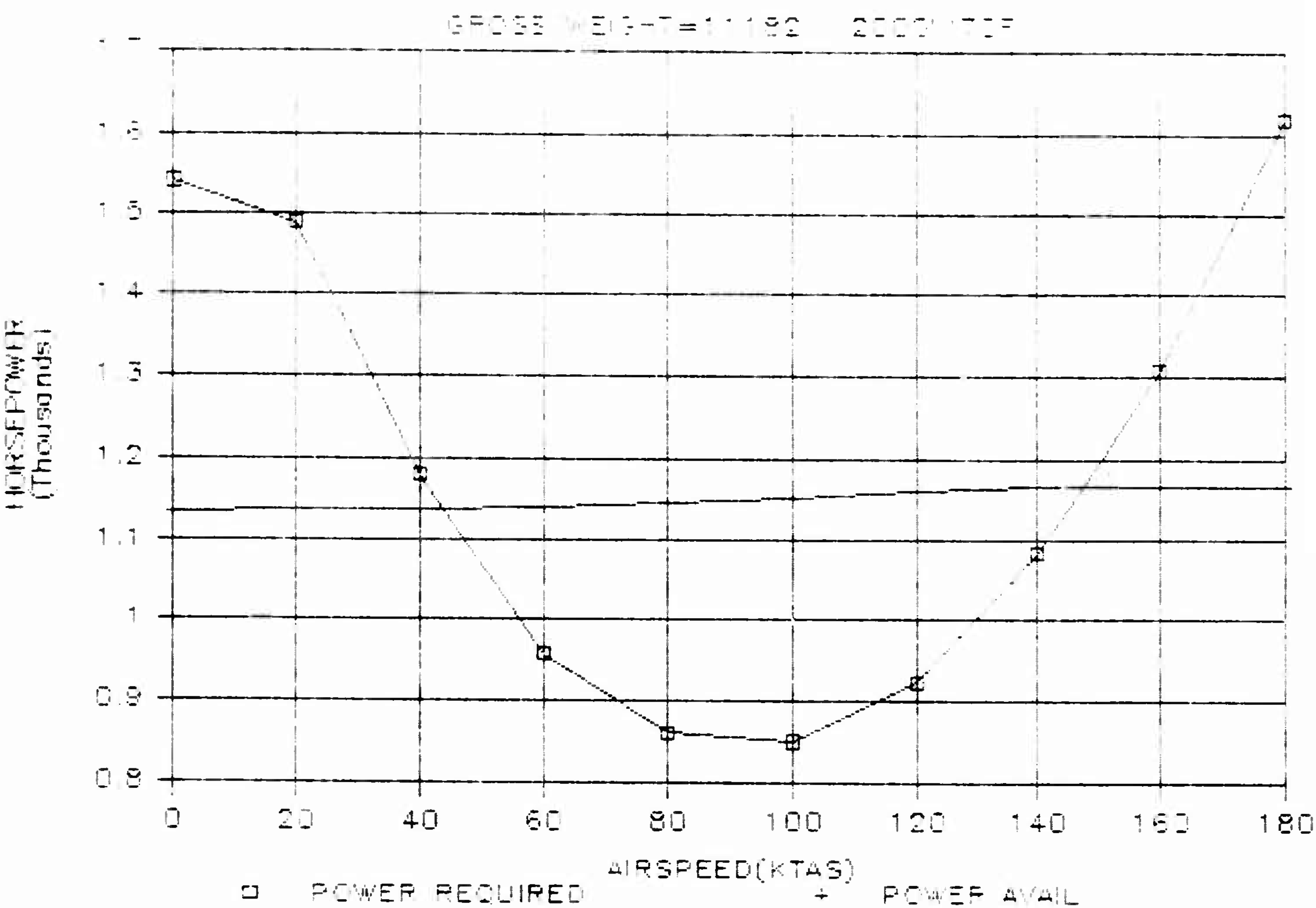

Figure N-VIII-14. SCAT ABC-compound OEI: 2,000'/70°F.

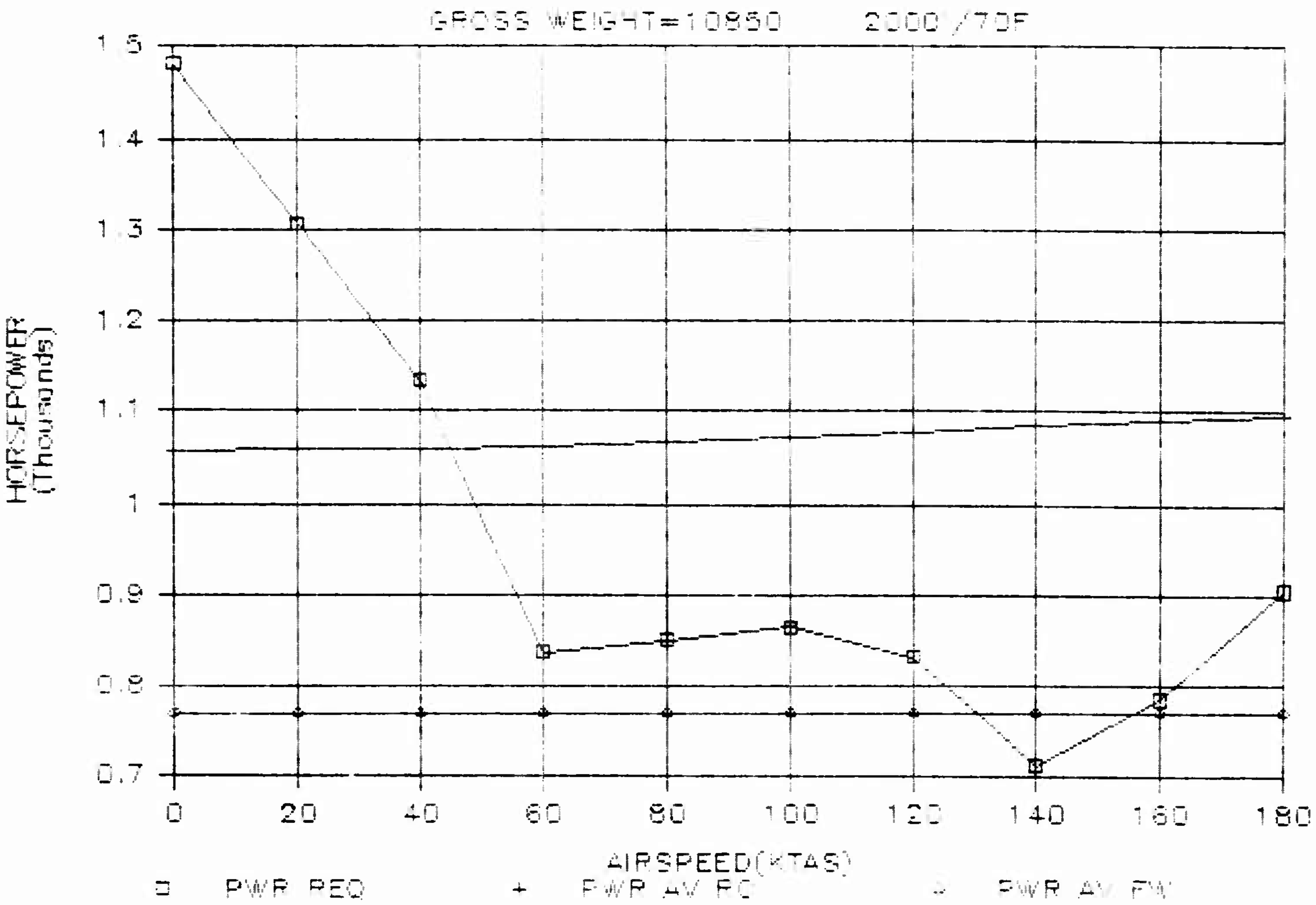

Figure N-VIII-15. SCAT tilt rotor OEI: 2,000'/70°F.

Table N-VIII-3. En route single-engine capability: Utility at 2,000 ft, 70°F/LHX TOD baseline designs.

Configuration	Single-Engine Airspeed Range (kt)	Gross Weight (lb)	Installed Engine Power (IRP at SLS)
Helicopter	49-132	9,096	959
Compound Helicopter	34-150	10,335	1,191
ABC	54-130	10,292	1,131
Compound ABC	58-140	11,182	1,339
TR			
Helicopter Mode	44-100+	10,850	1,244
Conversion Mode	100-140		
FW Mode	44-201		

(2) Utility. Off-design ambient condition performance capabilities for the Utility are presented in figures N-VIII-16 through N-VIII-20. The data presented is for the design gross weights. The single-engine results are presented in table N-VIII-4.

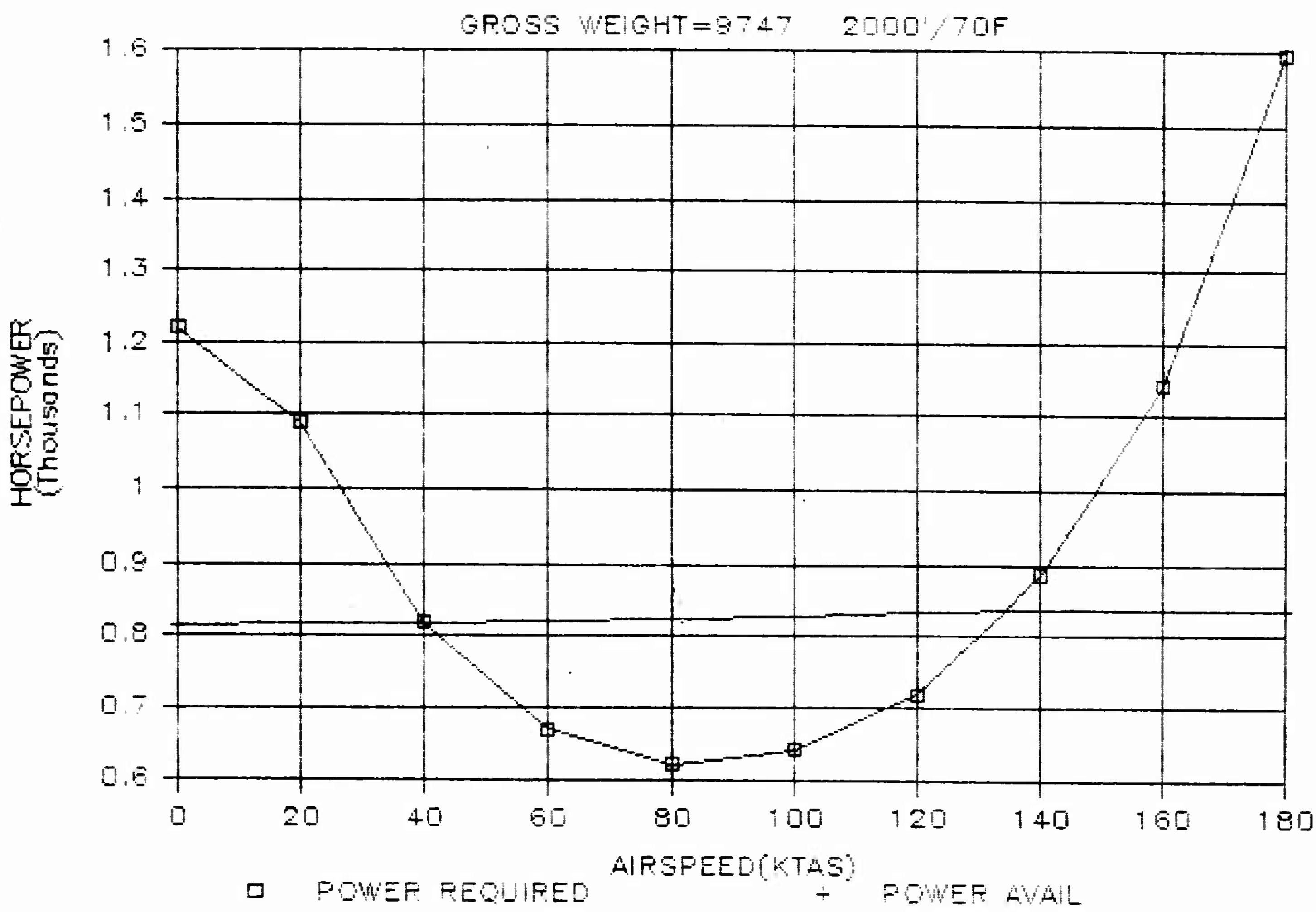

Figure N-VIII-16. Utility helicopter OEI: 2,000'/70°F.

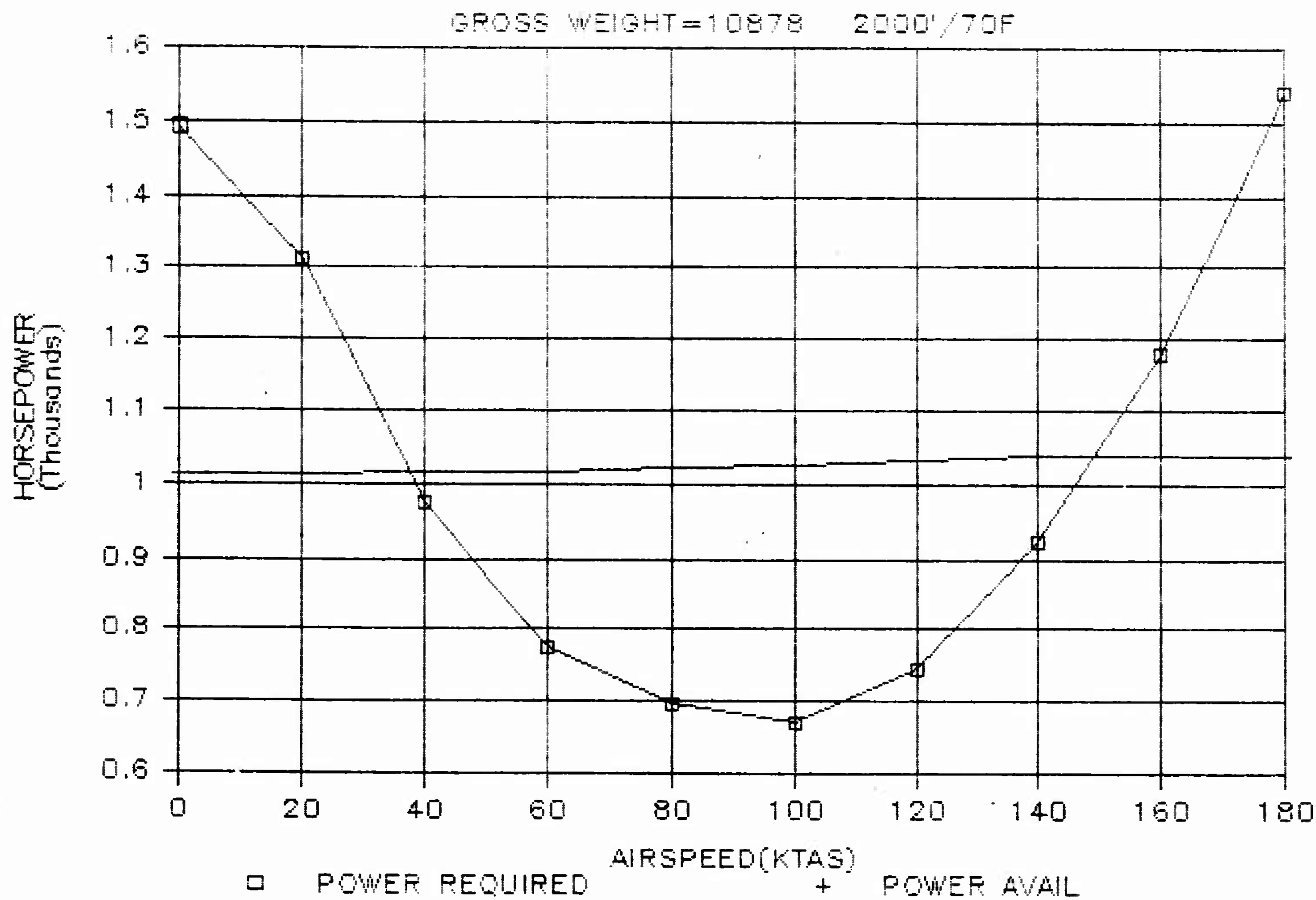

Figure N-VIII-17. Utility helicopter-compound OEI: 2,000'/70°F.

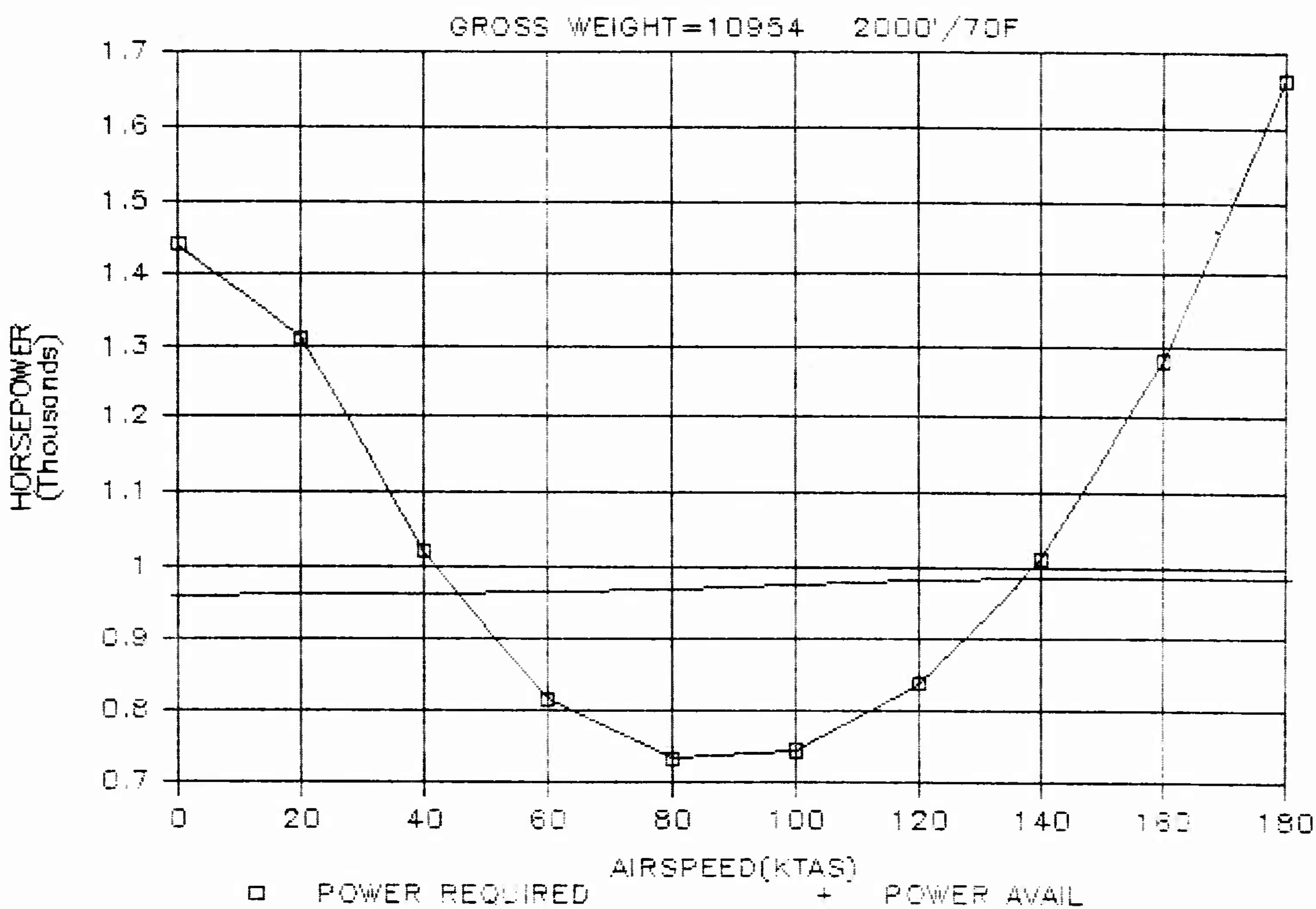

Figure N-VIII-18. Utility ABC OEI: 2,000'/70°F.

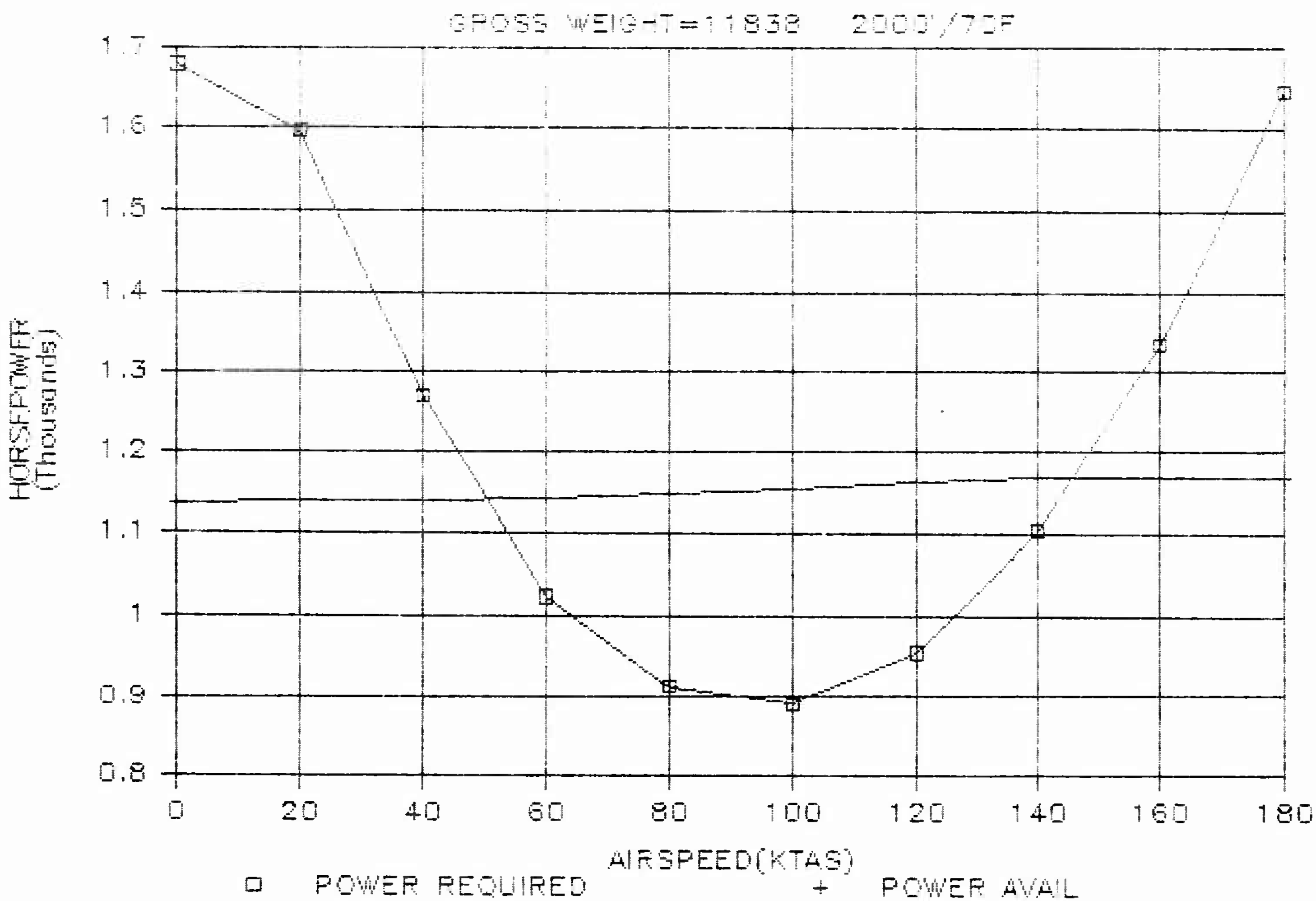

Figure N-VIII-19. Utility ABC-compound OEI: 2,000'/70°F.

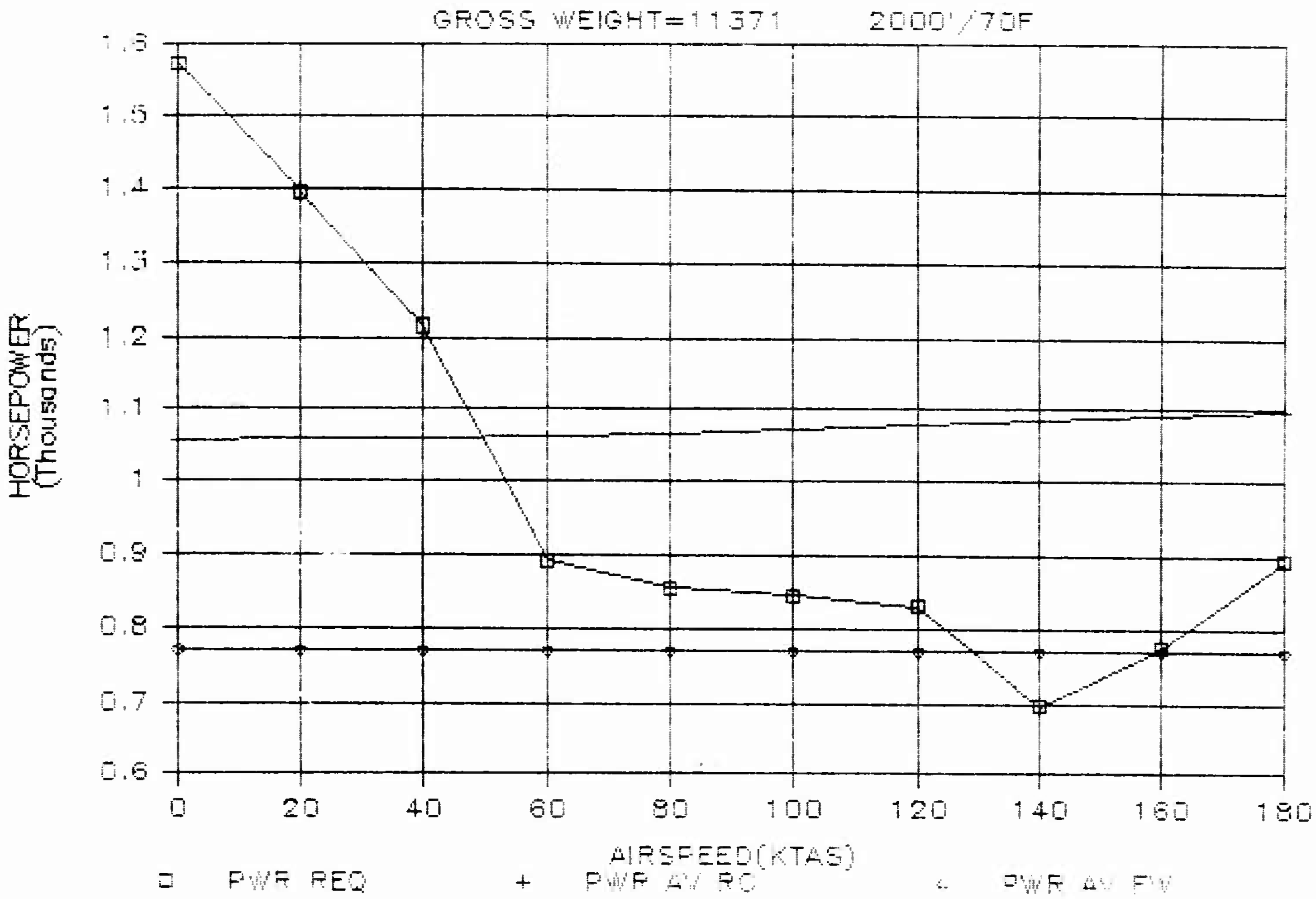

Figure N-VIII-20. Utility tilt rotor OEI: 2,000'/70°F.

Table N-VIII-4. En route single-engine capability: Utility at 2,000 ft, 70°F/LHX TOD baseline designs.

Configuration	Single-Engine Airspeed Range (kt)	Gross Weight (lb)	Installed Engine Power (IRP at SLS)
Helicopter	56-126	9,747	959
Compound Helicopter	38-149	10,878	1,191
ABC	48-144	10,954	1,131
Compound ABC	51-134	11,838	1,339
TR			
Helicopter Mode	50-100+	11,371	1,244
Conversion Mode	100-140		
FW Mode	50-202		

c. <u>Summary Charts</u>. SCAT and Utility summary charts are presented in figures N-VIII-21 and N-VIII-22.

N-VIII-6. FINDINGS.

a. <u>4,000 ft/95°F</u>.

(1) SCAT.

(a) All designs have en route single-engine capability.

(b) All configurations would have to off-load payload and/or fuel to perform a vertical landing.

(c) The TR and compound helicopter have the widest speed range with the compound helicopter having the lowest speed point and the TR having the highest speed point.

(d) The TR high speed interval is attained in the FW mode. In the helicopter mode, the upper limit is approximately 100 kt versus 181 kt.

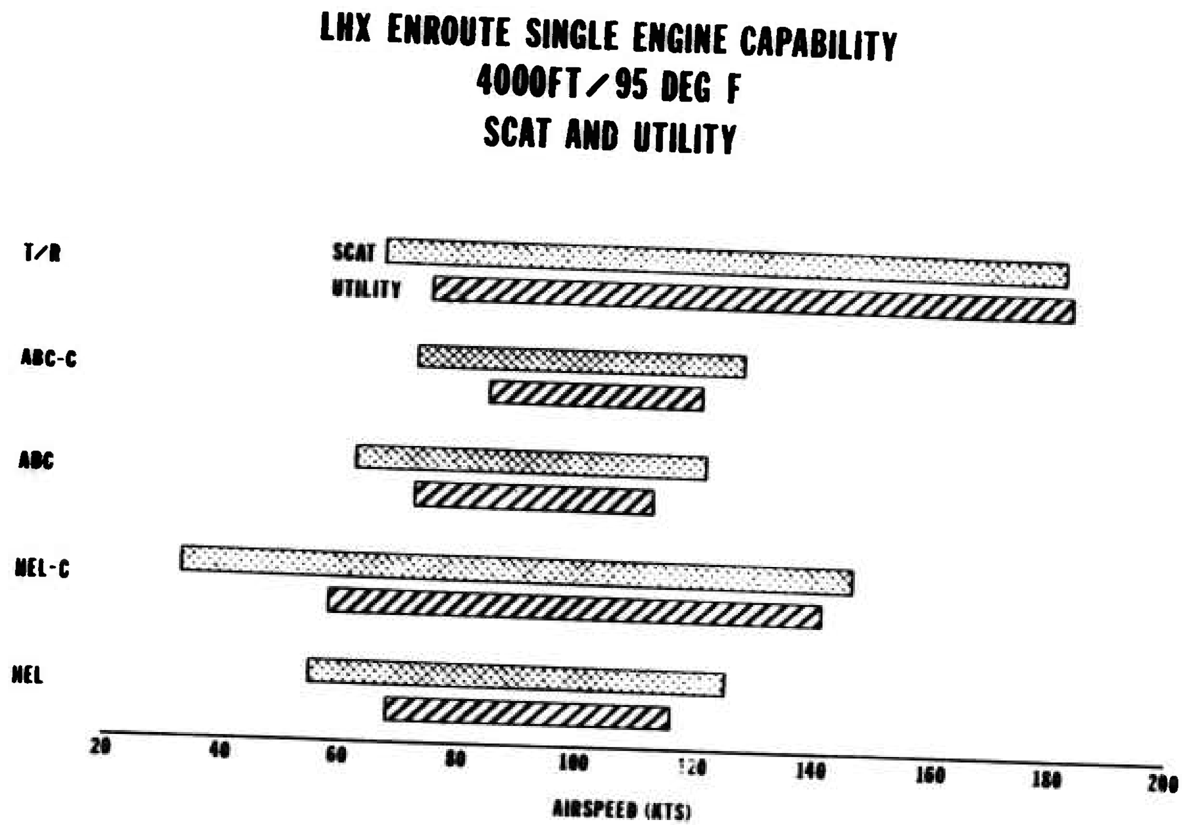

Figure N-VIII-21. SCAT and utility OEI summary, 4,000'/95°F.

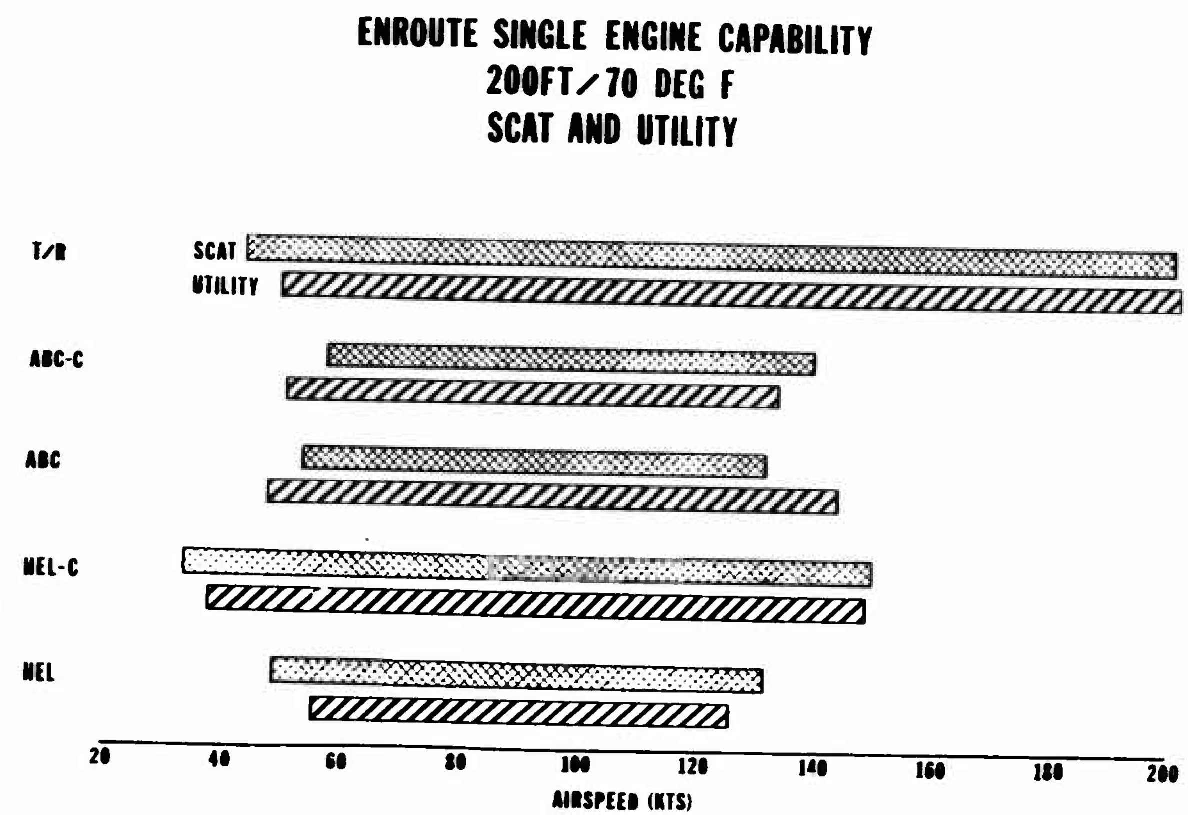

Figure N-VIII-22. SCAT and utility OEI summary, 2,000'/70°F.

(e) The rank order by inspection of the designs is:

1. TR and compound helicopter. (NOTE: The TR and compound helicopter rank equally.)

2. Helicopter.

3. ABC.

4. Compound ABC.

(2) Utility.

(a) All designs have en route single-engine capability.

(b) All configurations would have to off-load payload and/or fuel to perform a vertical landing.

(c) The TR and compound helicopter have the widest speed range with the compound helicopter having the lowest speed point and the TR having the highest speed point.

(d) The TR high speed interval is attained in the FW mode. In the helicopter mode, the upper limit is approximately 100 kt versus 182 kt.

(e) The rank order by inspection of the designs is:

1. TR and compound helicopter. (NOTE: The TR and compound helicopter rank equally.)

2. Helicopter.

3. ABC.

4. Compound ABC.

b. 2,000 ft/70°F.

(1) SCAT.

(a) All designs have en route single-engine capability.

(b) All configurations would have to off-load payload and/or fuel to perform a vertical landing.

(c) The TR has a substantially larger speed interval by using pylon tilt variability.

(d) The rank order by inspection of the designs is:

1. TR.

2. Compound helicopter.

3. Helicopter, ABC, compound ABC. (NOTE: The helicopter, ABC, and compound ABC rank equally.)

(2) Utility.

(a) All designs have en route single-engine capability.

(b) All configurations would have to off-load payload and/or fuel to perform a vertical landing.

(c) The TR has a substantially larger speed interval by using pylon tilt variability.

(d) The rank order by inspection of the designs is:

1. TR.

2. Compound helicopter.

3. Helicopter, ABC, compound ABC. (NOTE: The helicopter, ABC, and compound ABC rank equally.)

c. Overall. The TR appears to provide the best overall OEI capability, followed by the compound helicopter, helicopter, ABC, and compound ABC.

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ANNEX IX TO APPENDIX N

MULTIPLE ATTRIBUTE DECISION MAKING (MADM) ANALYSIS

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ANNEX IX TO APPENDIX N

MULTIPLE ATTRIBUTE DECISION MAKING (MADM) ANALYSIS

N-IX-1. PURPOSE. A multiple attribute decision making (MADM) analysis was performed to determine if, on the basis of selected parameters, one of the Light Helicopter Family (LHX) configurations presented in the Trade-Off Determination (TOD) would clearly be a preferred design.

N-IX-2. ASSUMPTIONS. The relative weightings of the selected parameters are equal.

N-IX-3. LIMITATIONS. Analysis is limited to scout-attack (SCAT) TOD designs.

N-IX-4. METHODOLOGY. The technique used was the "technique for ordered preference by similarity to ideal solution (TOPSIS)," developed at the United States Air Force Institute of Technology, Dayton, Ohio. The method consists of several steps which include establishing a decision parameter matrix with quantified values as presented in figure N-IX-1. The data matrix is then transformed into a normalized decision matrix as presented in figure N-IX-2. An element of the normalized decision matrix is calculated from the following:

$$R = X_{IJ} \Big/ \sqrt{\sum_{I=1}^{M} X_{IJ}^{2}}; \text{ for } I = 1, 2 \ldots M, \quad J = 1, 2 \ldots N$$

Configuration	Eng Pwr	D/L	Op Width	Msn Time	Wt Empty	Msn Fuel	VROC	R/C @ VBE
Helicopter	1,918	7	40.68	2	6,402	1,130	715	2,227
Helicopter-compound	2,382	8	40.56	2	7,424	1,348	779	2,656
Advancing Blade Concept (ABC)	2,262	9.5	37.14	2	7,388	1,341	713	2,270
ABC-compound	2,678	10.5	36.82	1.9	8,069	1,549	795	2,450
Tilt rotor	2,488	10	56.9	1.65	7,962	1,324	653	2,224

Configuration	VBR	V @ CP	Tlf/150	Slf/150	Tlf/90	Slf/90	Unit Dollars
Helicopter	135	164	1.82	1.67	2.2	1.73	7.091
Helicopter-compound	158	185	2.48	1.93	2.16	1.78	7.587
ABC	145	171	2.5	1.68	2.17	1.78	7.611
ABC-compound	158	186	2.5	1.8	2.18	1.76	7.97
Tilt rotor	216	245	2.19	1.78	1.64	1.3	7.776

Figure N-IX-1. LHX decision parameter data matrix.

Configuration	Eng Pwr	D/L	Op Width	Msn Time	Wt Empty	Msn Fuel	VROC	R/C @ VBE
Helicopter	.363	.3442	.4224	.4671	.3831	.3757	.4363	.4199
Helicopter-compound	.451	.3934	.4212	.4671	.4443	.4482	.4754	.5009
ABC	.428	.4671	.3856	.4671	.4421	.4458	.4351	.4281
ABC-compound	.507	.5163	.3823	.4437	.4829	.5150	.4851	.4620
Tilt rotor	.471	.4917	.5908	.3853	.4765	.4402	.3985	.4194

Configuration	VBR	V @ CP	Tlf/150	Slf/150	Tlf/90	Slf/90	Unit Dollars
Helicopter	.3757	.3813	.3518	.4208	.4727	.4604	.4165
Helicopter-compound	.4397	.4301	.4794	.4863	.4641	.4737	.4457
ABC	.4035	.3975	.4832	.4233	.4663	.4737	.4471
ABC-compound	.4397	.4324	.4832	.4536	.4684	.4684	.4682
Tilt rotor	.6011	.5696	.4233	.4485	.3524	.3459	.4568

Figure N-IX-2. Normalized decision matrix.

The normalizing process reduces extreme order of magnitude values to fractional values so that a particular column will not dominate the result to the extent that every other parameter is overshadowed. The relative importance of a parameter is then accounted for in the weighting value matrix presented in figure N-IX-3. The weights of each parameter were postulated to be of equal value because of the broad range of parameters selected which reflect the LHX conceptual definition. The weighted normalized decision matrix, figure N-IX-4, developed by applying the weighting values to figure N-IX-3 and the ideal and negative ideal solutions are determined by inspection (figure N-IX-5). The ideal solution is the one which gives the best value for a particular parameter. The negative ideal solution represents the worst value. Both are affected by the relative weighting values. The best value may be the high value or the low value in the column, depending on the parameter; i.e., a low "engine power required" is good, whereas a high value in the disk loading column would be bad. The next step in the procedure is to calculate the separation measures, which are measures of how far from the ideal and negative ideal solutions a particular configuration is located. The separation of each alternative from the ideal and negative ideal is determined by the following:

$$\text{Ideal} = \sqrt{\sum_{J=1}^{N} (P_{IJ} - P_{BEST})^2} \quad \text{for } I = 1, 2 \ldots M, \quad J = 1, 2 \ldots N$$

$$\text{Negative ideal} = \sqrt{\sum_{J=1}^{N} (P_{IJ} - P_{WORST})^2}$$

	Eng Pwr	D/L	Op Width	Man Time	Wt Empty	Man Fuel	VROC	R/C @ VBE
Weighting	1	1	1	1	1	1	1	1

	VBR	V @ CP	Tlf/150	Slf/150	Tlf/90	Slf/90	Unit Dollars
Weighting	1	1	1	1	1	1	1

Figure N-IX-3. Weighting values matrix.

Configuration	Eng Pwr	D/L	Op Width	Msn Time	Wt Empty	Msn Fuel	VROC	R/C @ VBE
Helicopter	.363	.3442	.4224	.4671	.3831	.3757	.4363	.4199
Helicopter-compound	.451	.3934	.4212	.4671	.4443	.4482	.4754	.5009
ABC	.428	.4671	.3856	.4671	.4421	.4458	.4351	.4281
ABC-compound	.507	.5163	.3823	.4437	.4829	.5150	.4851	.4620
Tilt rotor	.471	.4917	.5908	.3853	.4765	.4402	.3985	.4194

Configuration	VBR	V @ CP	Tlf/150	Slf/150	Tlf/90	Slf/90	Unit Dollars
Helicopter	.3757	.3813	.3518	.4208	.4727	.4604	.4165
Helicopter-compound	.4397	.4301	.4794	.4863	.4641	.4737	.4457
ABC	.4035	.3975	.4832	.4233	.4661	.4737	.4471
ABC-compound	.4397	.4324	.4832	.4536	.4684	.4684	.4682
Tilt rotor	.6011	.5696	.4233	.4485	.3524	.3459	.4568

Figure N-IX-4. Weighted-normalized decision matrix.

	Eng Pwr	D/L	Op Width	Msn Time	Wt Empty	Msn Fuel	VROC	R/C @ VBE
Best value	.363	.3442	.3823	.3853	.3831	.3757	.4851	.5009

	VBR	V @ CP	Tlf/150	Slf/150	Tlf/90	Slf/90	Unit Dollars
Best value	.6011	.5696	.4832	.4863	.4727	.4737	.4165

	Eng Pwr	D/L	Op Width	Msn Time	Wt Empty	Msn Fuel	VROC	R/C @ VBE
Worst value	.507	.5163	.5908	.4671	.4829	.5150	.3985	.4194

	VBR	V @ CP	Tlf/150	Slf/150	Tlf/90	Slf/90	Unit Dollars
Worst value	.3757	.3813	.3518	.4208	.3524	.3459	.4682

Figure N-IX-5. Ideal and negative ideal solutions.

These values are presented in figure N-IX-6. The subsequent step calculates the relative closeness to the ideal solutions as presented in figure N-IX-7.

Relative closeness = negative ideal - (ideal value + negative ideal value).

	Ideal	Negative Ideal
Helicopter	.353	.373
Helicopter-compound	.271	.349
ABC	.340	.326
ABC-compound	.365	.326
Tilt rotor	.376	.326

Figure N-IX-6. Ideal and negative ideal separation measures.

Helicopter	.513
Helicopter-compound	.562
ABC	.489
ABC-compound	.472
Tilt rotor	.464

Figure N-IX-7. Relative closeness values.

The final step is the preference order ranking, modeled to the extent that the candidate systems were normalized to the helicopter and are presented in figure N-IX-8.

Helicopter	1.000 (base case)
Helicopter-compound	1.094
ABC	0.953
ABC-compound	0.919
Tilt rotor	0.904

Figure N-IX-8. Normalized rankings.

N-IX-5. RESULTS/ANALYSIS.

a. The results of the analysis presented in figure N-IX-8 show the helicopter-compound to be 9.4 percent "better" than the helicopter which, in turn, is 4.7 to 9.6 percent better than the other candidate configurations. The results are based on the assumption that each parameter had equal weight and, based on the conceptional definition of the LHX (i.e., "small, lightweight, highly maneuverable/agile, low cost . . . "), the assumption is apparent as the 15 parameters address those parameters relative to the conceptional definition. In addition, selecting a broad range of pertinent parameters reduces the possibility of bias in the analysis to which the MADM technique is noted to be susceptible. This characteristic was investigated by a number of excursions which considered variations of the performance parameters only. The results are not presented herein as they distort the overall picture.

b. An alternate approach to evaluating the results is to plot the normalized value as a function of the percentage variation from the helicopter as in figure N-IX-9. The outlying of the helicopter-compound is apparent; a question arises that is directed toward the ABC-compound: "Why doesn't it stand above the ABC?" A possible explanation is the extent to which the ABC-compound preliminary design computer code was developed. The helicopter-compound considered in the analysis would not change the operating dimensional footprint of the helicopter and would cost approximately 7 percent more.

MULTIPLE ATTRIBUTE DECISION MAKING ANALYSIS
NORMALIZED RESULTS

REF: LHX TOD AIRCRAFT PERFORMANCE AND CHARACTERISTIC PARAMETERS

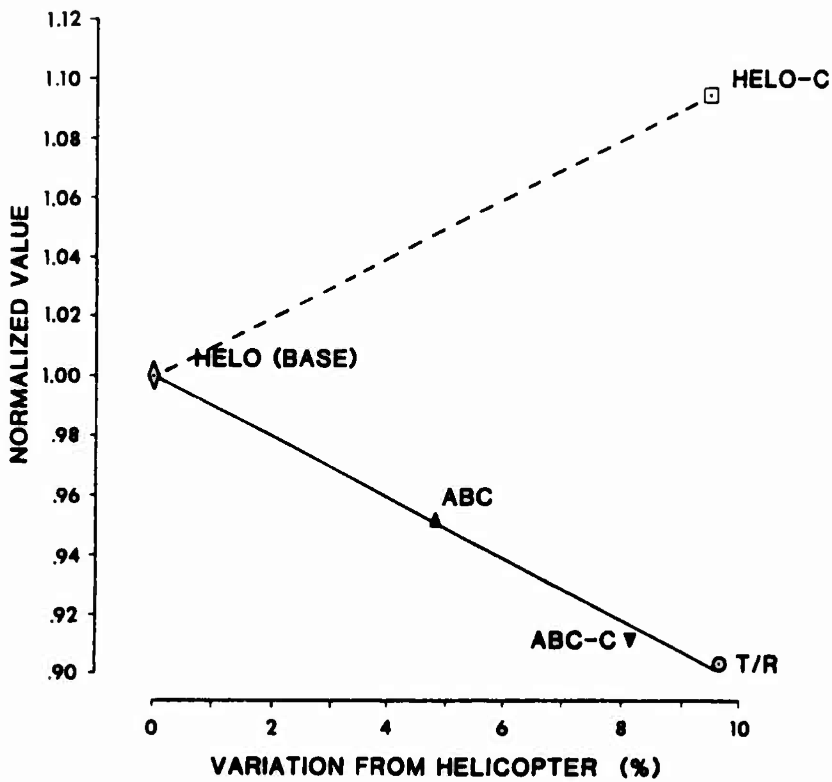

Figure N-IX-9. Normalized MADM results.

N-IX-6. FINDINGS/CONCLUSIONS.

a. Findings.

(1) Based on a broad range of characteristic parameters, each of equal weight, the helicopter-compound is the highest value system, followed in order by the helicopter, the ABC, the ABC-compound, and the tilt rotor.

(2) Varying the relative weights of the parameters significantly changes the outcome.

b. Conclusions.

(1) The helicopter-compound is the preferred system based on the method used and the associated parameters.

(2) Further effort should be directed toward perfecting the MADM technique to provide the insights to the benefits of the candidate designs.

ANNEX X TO APPENDIX N

AIRCRAFT PERFORMANCE AND ENGINE POWER MARGIN

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ANNEX X TO APPENDIX N

AIRCRAFT PERFORMANCE AND ENGINE POWER MARGIN

N-X-1. PURPOSE. The purpose of this substudy is to analyze the impact of providing the light helicopter family (LHX) with an engine that incorporates a built-in power margin.

N-X-2. BACKGROUND.

a. Gas turbine engines for Army aircraft have been required to grow subsequent to fielding (figure N-X-1) as a result of aircraft system growth (weight increases) and changes in requirements. Periodic growth in engine power has resulted in time lags and high cost penalties (AMC cost data indicate that a $1 design change made subsequent to production will cost the Army $1,000 to implement).[1]

b. Army helicopters typically experience empty weight increases on the order of 1-3 percent per year because of design changes, new equipment installation, and field repairs. The UH-60A (Black Hawk) has experienced an average empty weight increase of approximately 1 pound (lb) per production aircraft since it was fielded in 1979. Figure N-X-2 shows the actual empty weight (lb) increases and the trend which apparently has been established.

c. Changes in mission payload requirements and operational capabilities have historically been required, resulting in gross weight increases of the system. Figure N-X-3 depicts the variation of helicopter design gross weight and installed power with design altitude. A change in the design altitude criteria from 4,000 feet to 6,000 feet results in a gross weight increase of approximately 450 lb and a corresponding increase of 160 horsepower. Figure N-X-4 shows the increase in gross weight the Black Hawk has experienced due to the addition of blade deice and external stores support system (ESSS) and the projected gross weight increases due to the hover infrared suppressor system (HIRSS) and improved main gear box (MGB). Also shown on figure N-X-4 is the current maximum takeoff gross weight (TOGW) of the T700-700 and T700-700/+5-percent engines. Additional changes in the operational capability of the Black Hawk currently being defined in the required operational capability (ROC) for the Black Hawk Improvement Program will substantially increase the gross weight, causing an additional increase in power required. A 6-year engine development program costing approximately $120M will be required to provide this additional power.

N-X-3. ASSUMPTION. There exists a need for built-in power margin in the LHX to accommodate future system growth requirements.

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1. Annex 1, Appendix O, Volume IV, Advanced Scout Helicopter (AHS) Special Study Group Final Report, December 1979.

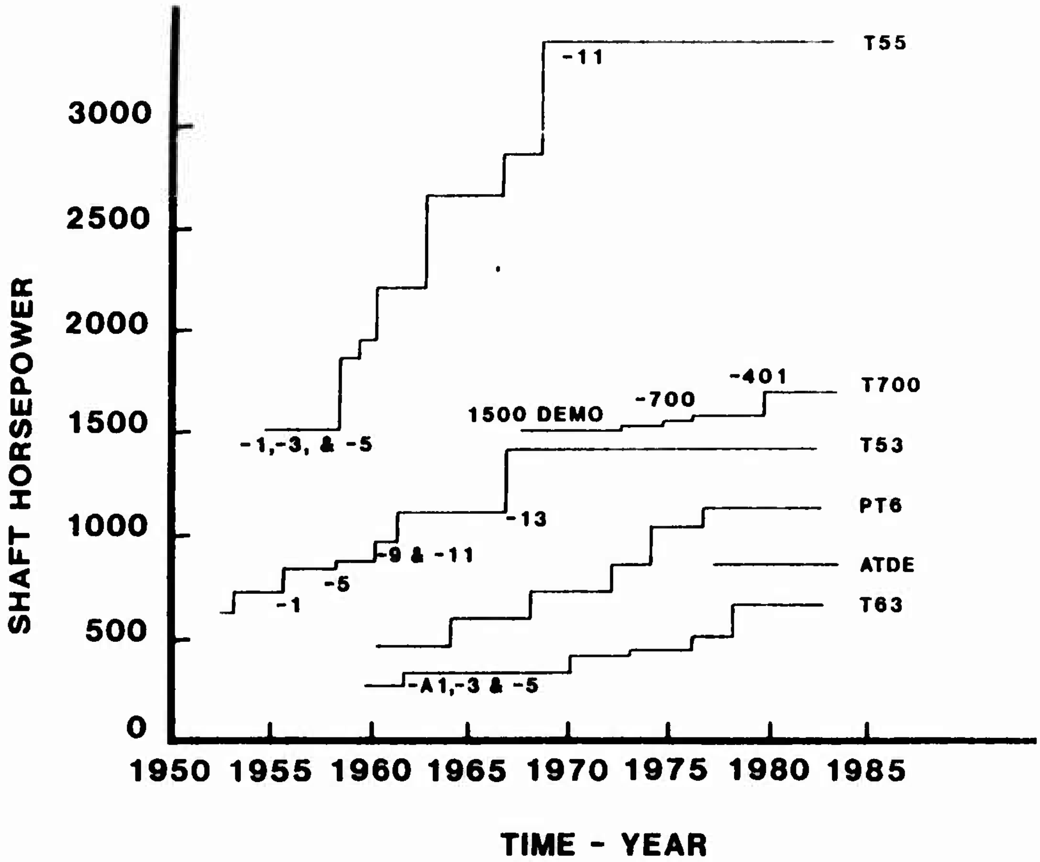

Figure N-X-1. Turbine engine growth history.

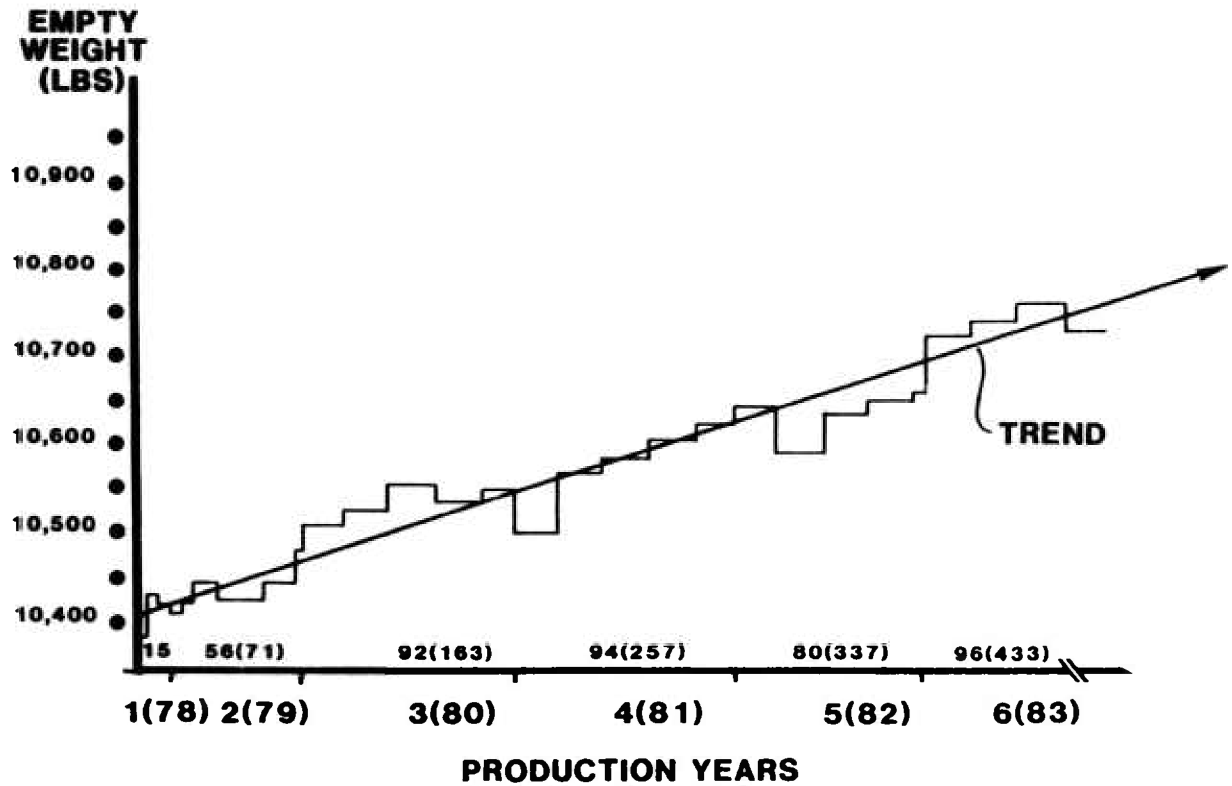

Figure N-X-2. UH-60 weight growth.

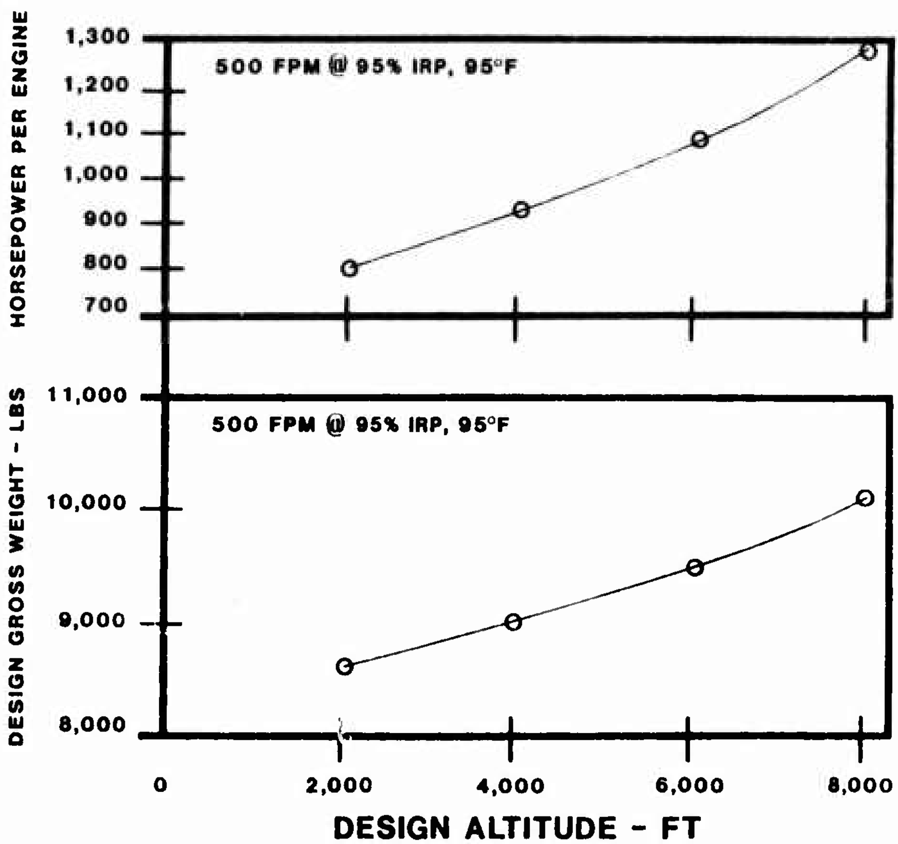

Figure N-X-3. Variation of helicopter gross weight and installed power with design attitude.

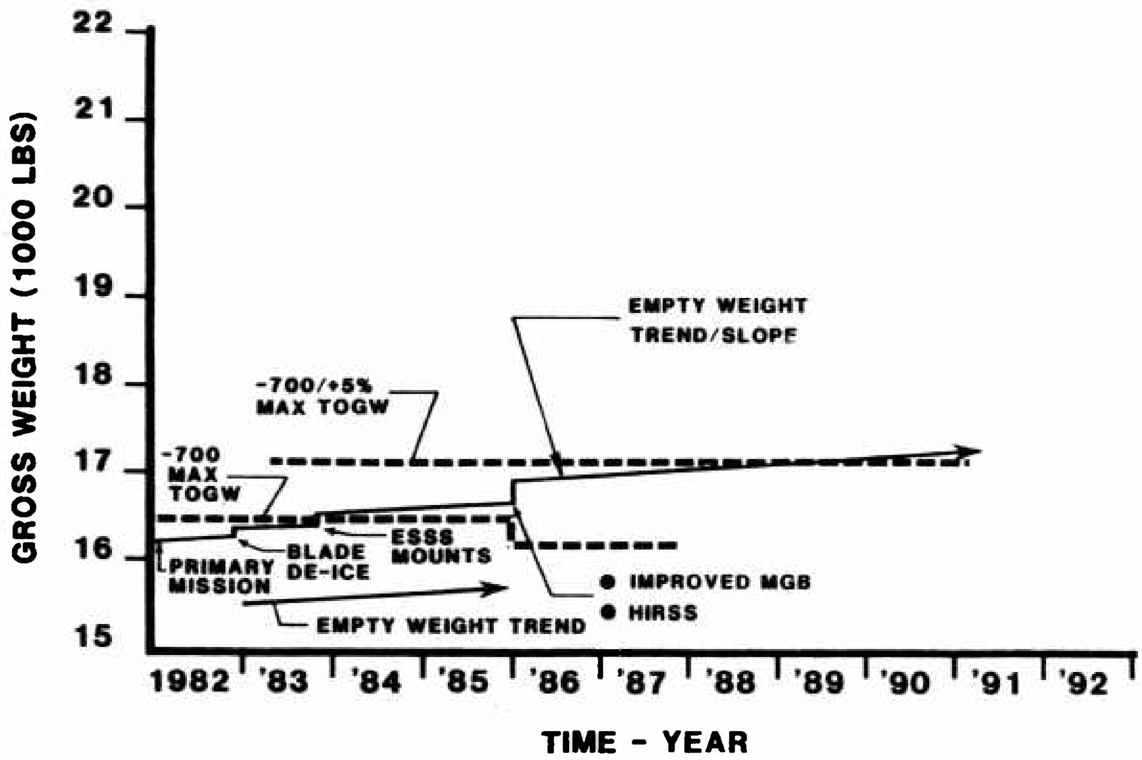

Figure N-X-4. UH-60 gross weight increase.

N-X-4. METHODOLOGY.

a. The analysis was conducted using the results of the Trade-off Determination (TOD) Scout-Attack (SCAT) and Utility designs as a baseline. The baseline designs included a helicopter, compound helicopter, advancing blade concept (ABC), compound ABC, and a tilt rotor (T/R). Maintaining a constant 1,030-lb payload for the SCAT variant performing mission 16, the engine and drive system were oversized by 25 percent. The results of oversizing the propulsion system was compared to the baseline designs. The Utility variants were analyzed for mission 35 as a fallout of the SCAT analysis.

b. The cost analysis was conducted using the baseline unit flyaway cost factors and a comparison of fuel consumption rates. The unit flyaway cost equation for the analysis was:

$$\text{Cost (M\$)} = K + C\ [A\ (W_E) + W_{EAP} + MEP + ENG]$$

Where K = .10 SCAT and .09 Utility

C = 1.124 SCAT and 1.170 Utility

W_E = Empty weight (no MEP)

W_{EAP} = Weapon cost = .365

MEP = MEP cost = 3.976

ENG = $622 \times 10^{-6} \times$ HP (one engine)

A = 344×10^{-6} all but T/R for SCAT

= 324×10^{-6} T/R for SCAT

= 336×10^{-6} all but T/R for Utility

= 317×10^{-6} T/R for Utility

Fuel consumption costs were based on an assumed fuel cost of $1.23 per gallon.

N-X-5. RESULTS/ANALYSIS.

a. Sizing an engine with a built-in power margin will impact weight, fuel consumption, and cost of the aircraft system. The design of an engine larger than required to accommodate potential changes in system weight or requirements will necessitate an increase in component weights of the engine, drive train, and fuel systems. The system gross weight is further increased as a result of increased fuel weight resulting from off-optimum operation of the propulsion system.

b. The results of the substudy analysis are provided in figures N-X-5 and N-X-6. Figure N-X-5 shows the impact of a 25-percent power margin on the empty weight, fuel burned, and gross weight of the five LHX system variants for both the SCAT and Utility. The increase in system weights is on the order of 5-8 percent and the fuel consumption is increased by approximately 10-12 percent for the SCAT and 15-19 percent for the Utility. Figure N-X-6 shows the resultant impact on cost. The unit flyaway cost is increased by approximately 3-7 percent and the 20-year fuel cost (assuming the power margin is not required) is increased by approximately 10-20 percent.

N-X-6. FINDINGS. While the weight and cost impact of providing an engine with power margin is significant, the potential gains in improved mission performance capability and system growth potential appear to warrant developing an engine with a built-in power margin.

SCAT

	Helicopter			Helicopter Compound			ABC			ABC Compound			Tilt Rotor		
	BL	OS	Delta	BL	OS	Delta	BL	OS	Delta	BL	OS	Delta	BL	OS	Delta
Horsepower	959	1,199	240	1,227	1,534	307	1,131	1,414	283	1,339	1,674	335	1,243	1,555	312
Empty weight (lbs)	6,402	6,799	397	[illegible]	8,048	547	7,389	7,954	565	8,069	8,748	679	7,958	8,406	448
Fuel burned (lbs)	953	1,048	95	1,175	1,315	140	1,132	1,256	124	1,298	1,446	148	1,089	1,200	111
Gross weight (lbs)	9,097	9,611	514	10,453	11,173	720	10,292	11,010	718	11,182	12,043	861	10,842	11,456	644

UTILITY

	Helicopter			Helicopter Compound			ABC			ABC Compound			Tilt Rotor		
	BL	OS	Delta	BL	OS	Delta	BL	OS	Delta	BL	OS	Delta	BL	OS	Delta
Horsepower	959	1,199	240	1,227	1,534	307	1,131	1,414	283	1,339	1,674	335	1,243	1,555	312
Empty weight (lbs)	6,321	6,548	227	7,375	7,944	569	7,319	7,932	613	8,004	8,619	615	8,026	8,524	503
Fuel burned (lbs)	1,167	1,362	195	1,306	1,501	195	1,351	1,605	254	1,505	1,777	272	1,045	1,198	153
Gross weight (lbs)	9,747	11,533	1,786	10,959	12,943	1,984	10,954	13,153	2,199	11,838	14,033	2,195	11,370	12,396	2,026

NOTE: BL = Baseline design.
OS = Oversize design.

Figure N-X-5. Built-in power margin impact.

POWER MARGIN COST IMPACT											
		Helicopter		Helicopter Compound		ABC		ABC Compound		Tilt Rotor	
		$M	Percent	$M	Percent	$M	Percent	$M	Percent	$M	Percent
Delta flyaway	SCAT	638	3	898	4	886	4	1,062	5	699	3
	Utility	514	4	870	7	870	7	945	7	580	5
Delta 20-year fuel cost	SCAT	122	10	176	12	156	11	184	11	140	10
	Utility	164	17	164	15	214	19	213	18	129	15
Total cost impact		$1,438M		$2,108M		$2,126M		$2,404M		$1,548M	

Figure N-X-6. Cost impact of built-in power margin.

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